An Adaptive Policy Routing with Thermal Field Approach

Lada-On Lertsuwanakul, Herwig Unger

Faculty of Mathematics and Computer Science
FernUniversität in Hagen
Universitätsstraße 27 - PRG
58084 Hagen
lada-on.lertsuwanakul@fernuni-hagen.de
herwig.unger@fernuni-hagen.de

Abstract: This paper introduces an adaptive routing approach based on buffer status and distance in a mesh overlay network: Thermal Field is used for considering buffer stage and distance is applied to select routing policy. The path selection process considers the Thermal Field as a metaphor for the buffer usage based on probability in order to avoid message loss by overloaded peers or delay because of big queues, otherwise routing by the shortest way. In addition, the probability of Thermal Field consideration relies on leftover distance to the target instead of using a global constant. The experiment results substantiated our approach using the adaptive probability of routing mechanism works effectively.

1 Introduction

The boom of the internet applications today requires better support for Quality of Service (QoS). Unfortunately, there are many factors from both, human and technical side, causing low internet performance. The problems still exist, such as packet-drop when sent to peers with overloaded buffers, packet-delay when residing in large queues or using indirect routes, and packets expired. The goals of QoS routing are usually not only to select the best path for sending information from source to destination effectively but also to provide efficient network utilization. Many algorithms [Ab07], [XG07] have been developed in this research area. Some of them are computing optimal routes considering two- or more constrains, especially bandwidth and hop-count, but only a few that concerned buffer space.

In addition to the efficiency of the algorithm, the routing performance also relies on the network-architecture. The modern internet structure emerges, e.g. in Peer-to-Peer (P2P) networks organized in virtual community overlay-network working on the basic protocol level [Lu04]. The structured overlay networks use Distributed Hash Tables (DHT) to identify a relationship among nodes and files for routing control. Such a structure finds data potentially, but does not support complex lookup requests. Also it affects when any nodes leave without notification. Whereas, the unstructured types organize peers in a random graph or hierarchical, and use flooding or random search on the graph to find the desired content. Each peer queries its own content locally so it supports complex queries.

A grid architecture is interesting because of Kleinberg's work [Kl00]. He has introduced a decentralized algorithm in grids with added long-range links and proofed it was able to forward messages from any source node to target within finite delivery time. Moreover, Berg et. al. [BSU09] have shown cartesian coordinate system is possible to generate in grid on top of the large-scale decentralized network.

Those are our motivations to introduce an adaptive algorithm for a 2-dimenstional coordinate space overlay on unstructured P2P networks using thermal field to deal with buffer stages. High temperature means high buffer utilization. The optimal path emerges from the low isotherms. In the first stage of research [LU09], the constant probabilities set up globally were introduced. The results of simulation demonstrated Thermal algorithm that can work efficiently for considering buffer status. One global value, however, cannot fit to all communication network conditions, especially when analyzing the remaining distance. Though, the adaptive probability ideas are introduced in this paper. The packet will be forwarded by fastest policy or adaptive policy based on a probability formula which is the function of remaining distance from current location to target node. The closer packets move to the target, the more packets use the direct path.

This paper is organized as follows: Section 2 discusses classical routing algorithms on meshes and thermal field algorithms used for searching in P2P networks. Section 3 introduces an adaptive probability of our routing strategy using the thermal field approach. Section 4 describes the simulation environment P2PNetSim, respective the results and discussions. Finally, Section 5 concludes the paper and gives an outlook for future research.

2 Related Work

2.1 Classical Routing on Mesh Networks

Mesh topologies have been used in many areas of communication networks. The mesh network is reliable and offers redundancy of the connection.

The mesh scheme is applicable to packet/circuit switching in both wireless networks [LW04], [RR91] and wired networks [CL92], [JVM95], vehicle problems and software interaction. The routing algorithm generally is the process to define paths for sending data from a node to another through the network traffic. The goals of routing algorithm are providing fastest or shortest path, preventing deadlocks, ensuring low latency, balancing network utilization, and fault tolerance. There are some typical routing algorithms in mesh-connected topologies [Me04].

1. A deterministic method is called "XY routing algorithm". Packets route along X direction and change to Y direction when reaching the Y value of the target.

2. The partial adaptive algorithms, "West-First", "North-Last", and "Negative-First". Packets route with deterministic algorithms in specific conditions; otherwise, packets route by using a function that reacts immediately on network traffic.

Routing by these classical methods, there are multiple paths having same hop count. The source node wants to send information to the target node. Then the best path depends on which algorithm is selected. The chance to find low QoS relies on the path selection function. If the selected route has many overloaded peers, then delay time increases or the packet loss occurs.

2.2 Thermal Algorithms

The Thermal Field approach has been introduced by Unger and Wulff [UW04]. It is used for searching nodes in P2P networks that keep the desired data. The special information can be a very frequently accessed data or recently update information. The temperature implies the intensity of the activities or changes of specific information in the node in the web community. Further, when a high temperature point occurs in the community, its heat spreads around. The spreading temperature decreases by distance between heat source and measurement point, also by distribution time; the same effects can be observed in the part of human body. Finally, a point becomes colder if there is no heat fed in.

The thermal approach can be applied to a P2P environment when the assumption is made that members of the community cooperate with each others, and all peers contribute for community results. Whenever there is a message sent among members of the community, it means the heat is transported from source to neighbor. However, there is a difference from nature that the virtual community is able to memorize temperatures from latest access of each neighbor. Consequently, when a message requests for a special information, it can be transferred to the "hottest" neighbor that is kept in memory.

Section 2 presented some existing routing algorithms on mesh- or grid-like networks. The approaches work effectively; however, their performance should be better if more constraints are considered. Further, original thermal field approach is described for searching specific information in P2P networks. The next section explains how the thermal field algorithm works to find routes and how the functions make the policy selection process flexible.

3 Algorithms

Our approach considers buffer stages to find optimal paths. The thermal field is used for communicating buffer information over the network. So that, every node has to keep its neighbors' temperatures and ID. The lower temperatures represent more available resources to handle new data. However, the main routing goal usually is to find the fastest way. Then the balance of direct way and adaptive way must be defined properly. Hence, the suitable probability leads to global resource utilization and the optimal path. Based on a grid structure, our approach uses the euclidean distance for measuring the length between nodes. In the route decision process, the distance of original to target node, the length of current to target peer, and the distances of neighbors to target location are measured.

By these results, the shortest path can be measured, and the relative distance among interested locations can be calculated.

3.1 Measuring the Temperature

In our algorithm, the temperature θ represents the buffer usage of a peer that is the level of messages waiting to forward. At a current node *c*, the temperature θ_c is calculated at every simulation time. The value of θ_c is between 0 and 1: 0 denotes an empty buffer and 1 a full buffer.

$$\theta_c = \frac{\text{Messages in Buffer}}{\text{Buffer size}}, \qquad 0 \leq \theta_c \leq 1$$

The latest buffer status is important to make a correct decision; hence, it is designed to attach the temperature value to all data packets sent through the community and in the corresponding acknowledgement packets. The packets and the acknowledgements work as a median of the temperature. They pass temperatures from one to another node until they reach their target or expire.

Every current node *c* has a set of neighbors $N(c)$ where messages can be forwarded to and *i* is a number of neighbor, then $N_i \in N(c),\ 1 \leq i \leq 4$. There are three possibilities to update a neighbors' temperature, $\theta(N_i)$ on node *c*. Let β_i be the number of packets and μ_i be the number of acknowledgments which sent from neighbor N_i to current node.

1. If node *c* receives a packet or an acknowledgment from neighbor N_i , the old temperature is replaced with the new temperature.

$$\theta(N_i) = \theta_i, \qquad if\ \beta_i>0\ and\ \mu_i>0$$

2. If there is no message sent from neighbor N_p , the new temperature caused by the spread of source node then decreases exponentially, whereby *t* is the routing time.

$$\theta(N_i) = \theta(N_i) \cdot e^{-\lambda t}, \qquad if\ \beta_i=0\ and\ \mu_i=0$$

3. The new temperature is zero when no message arrives and no heat remains.

$$\theta(N_i) = 0, \qquad if\ \beta_i=0,\ \mu_i=0,\ and\ \theta(N_i)=0$$

Our algorithm selects the routing policy by the probability of using thermal field. At the starting point of ongoing research, the probabilities used for selecting the fastest path or adaptive paths were defined as global parameters, as presented in [LU09]. The seven predefined probabilities are tested in the P2PNetSim simulator. All constant probabilities showed the effective results of the algorithm, however, neither of them fully fits all communication network conditions. For example, when the node wants to forward the packet which is close to its target, the low buffer path might be maintained for a long routing time instead of forwarded directly the remaining steps with a little more delay. Hence, the high buffer route with the fewer intermediate nodes has higher potential for routing a packet than low buffer paths with longer routing times. Usually there is no need to use route policies equally, so the shortest routing policy is predominant over thermal approach in these conditions. Therefore, an adaptive probability for flexible routing is necessary for considering distances. Next topic, we introduce five adaptive possibilities which are initiated by tuning the results from one experiment to another.

3.2 Adaptive probability for route selection

The path selection step is related to a probability for using temperature data, P_θ . Each node randomly selects a low-buffer route according to P_θ, otherwise selects a direct route. If P_θ is high, that means more chances to select a low buffer route, then it leads to long a routing time. On the other hand, a small P_θ, raises the high chance to select a direct route, and comes up with message loss due to overloaded nodes along the shortest way. Though, the optimal route and load balanced network are a result of a best probability.

The adaptive probability formulas (AP_θ) are both linear and exponential functions of relative remaining distance Ω during the routing time t. When a source node s sends a packet to destination node φ, the distance between original peer and a target peer is $d_{s2\varphi}$. At a current node c that is going to decide for a path to forward message to, the distance between current node and target node is $d_{c2\varphi}$.

$$\Omega(t) = \frac{\text{Distance\_from\_current\_to\_target}\ (t)}{\text{Distance\_from\_source\_to\_target}\ (t)} = \frac{d_{c2\varphi}}{d_{s2\varphi}}$$

The Adaptive Probability1 *(AP_θ^1)*: The AP_θ^1 formula is a linear function. The probability of using thermal field is on interval [0, 1] by the value of remaining distance, Ω. But the probability is always equal to 1 when the current node is farer from target than the original node. The graph of probability is presented in Fig. 1(a).

$$\text{Probability of } AP_\theta^1 = \begin{cases} \Omega, & d_{c2\varphi} \le d_{s2\varphi} \\ 1, & d_{c2\varphi} > d_{s2\varphi} \end{cases}$$

Other adaptive formulas are exponential distribution functions which the rate parameter (λ) is equal to 1 in this paper.

The Adaptive Probability2 *(AP_θ^2)*: The AP_θ^2 is converted from a linear function to an exponential function. The range of probability is [0, 1], shown in Fig. 1(a), similar to AP_θ^1 but increases exponentially when the current node is on the path between source and target peer.

$$\text{Probability of } AP_\theta^2\ (\Omega;\lambda) = e^{-\lambda\left(1 + \frac{1}{\Omega(t)}\right)}$$

The Adaptive Probability 3 *(AP_θ^3)*: The AP_θ^3 is the exponential probability density function (pdf) of inverse remaining distance. The probability of using thermal is on interval [0, $e^{(-1)}$] when decision node is located between source and target node. On the other hand, when indirect route is selected, the probability of using thermal field is higher according to the farer distance.

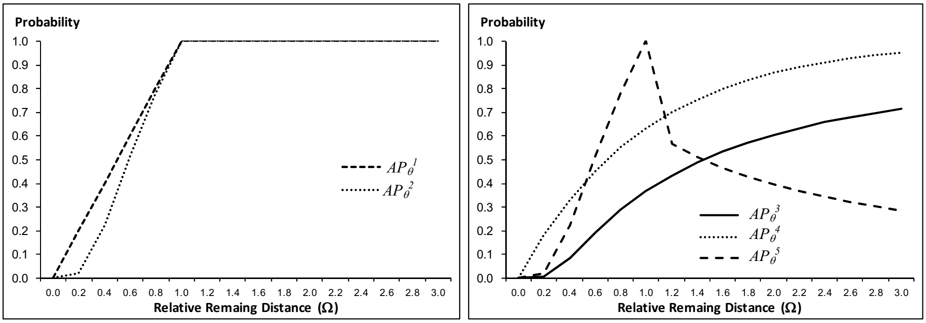
$$\text{Probability of } AP_\theta^3\ (\Omega;\lambda) = e^{\left(\frac{-\lambda}{\Omega(t)}\right)}$$

The Adaptive Probability4 *(AP_θ^4)*: The AP_θ^4 formula is an exponential cumulative distribution function (cdf). The probability of using Thermal field is on interval [0, 1). This adaptive idea means when decision node is closer the target, the probability of using thermal field is higher.

$$\text{Probability of } AP_\theta^4\,(\Omega;\lambda) = 1 - e^{(-\lambda \cdot \Omega)}$$

The Adaptive Probability5 *(AP_θ^5)*: The AP_θ^5 idea is a combination of the formulas for direct and indirect paths. When decision node is closer to the target than the original node; the probability of thermal field decreases. Also, if decision node is farer away from the target than the source, the probability of using temperature decreases.

$$\text{Probability of } AP_\theta^5\,(\Omega;\lambda) = \begin{cases} e^{-\lambda\left(1 + \frac{1}{\Omega(t)}\right)}, & d_{c2\varphi} \le d_{s2\varphi} \\ 1 - e^{\left(\frac{-\lambda}{\Omega(t)}\right)}, & d_{c2\varphi} > d_{s2\varphi} \end{cases}$$



(a) (b)

Fig. 1: The graph of adaptive probability functions when λ = 1

This section presented the details of the adaptive probability idea for routing with the thermal field approach to consider buffer stages. Next in Section 4, we present some experimental results of adaptive probability functions compare with predefined probability parameters that we introduced in [LU09].

4 Experimental consideration

4.1 Environment Setting

The simulation tool – The experiment was simulated using P2PnetSim a network simulation environment [Co06]. The tool is powerful and flexible in simulating, modeling and analyzing any kind of networks, not only computer networks but also social networks, RFID-processing and spreading of ineffectual diseases. It is able to manage more than one million nodes. Peers can be configured collectively and individually using XML files for simulation setup. Peer-Behavior is implemented in the Java programming language.

The network – In our experiments, the network is organized into a grid structure with 10,000 nodes in two dimensions (100x100). The coordinates of a node within the grid form its node ID. The grid is overlaid on a virtual IPv4 network. Peers are connected in four directions to each other: left, right, up, and down. The buffer sizes and outgoing bandwidths are limited for most of the peers. Both buffer sizes and bandwidth values are assigned randomly follow the Pareto distribution. There are two types of packets, data packets and acknowledgements. The acknowledgment is prioritized. Otherwise, the system handles the packets First-In-First-Out.

The traffic pattern – To generate traffic, the simulation defines different throughputs for nodes in terms of buffer sizes and outgoing bandwidths. In the trial, the 50 source nodes are randomly selected sending messages to four target nodes. They generate a message every 3rd simulation step until simulation-time has reached 300.

The performance metric – In order to evaluate algorithm performances, the following metrics are measured:

- number of messages loss
- number of messages arrive their targets
- routing time that counts from launching the original node to reaching the target node. That time includes moving steps and waiting times in the traffic nodes.
- delay time that summarizes from waiting times because of high queues since launched from original node until reaching the garget.
- number of nodes that have the buffer usage more than 70%. Our assumption, this level is the starting point that cause overloaded buffer situation.

4.2. Results and Discussion

The experiments reported in this section compare seven global parameter probabilities: Fix-P0.1, Fix-P0.3, Fix-P0.4, Fix-P0.5, Fix-P0.6, Fix-P0.7, and Fix-P0.9 from simulation results in [LU09], and five adaptive probability functions which have been described previously. In experiments, a message is generated and forwarded every three simulation steps by 50 source nodes that sent to specific four target locations. The source peers stopped sending at simulation time 300.

The message is forwarded through the network until one of these cases happens: the message reaches its target, the time-to-life of the message reaches zero, or the message is deleted by an overloaded buffer. The exponential rate parameter (λ) is equal to 1.

Fig. 2 shows the comparison of the ratio with three key performance metrics: messages arrive their target, messages lose due to overload buffers, and messages expire before they have found their targets. The AP_θ^5 shows the best result among the adaptive ones, 88% reached target and 12% lost. However, a fixed probability of 0.6 presents better results which is 100% reach their targets and no message lose and expire. In contrast, AP_θ^1 *and* AP_θ^2 are inefficient to reach the target. About 40% of all messages reach the goal, but others lose and expire. By the way, Fix-P0.9 is the worst, only 6% of the messages are able to reach their target, and 93% expire.

Our assertion is with too high probability (e.g. Fix-P0.9) and too low probability (e.g. Fix-P.0.1, AP_θ^1, AP_θ^2) are ineffective, the optimal route can be found by balancing both policies (e.g. Fix-P0.5, AP_θ^4).

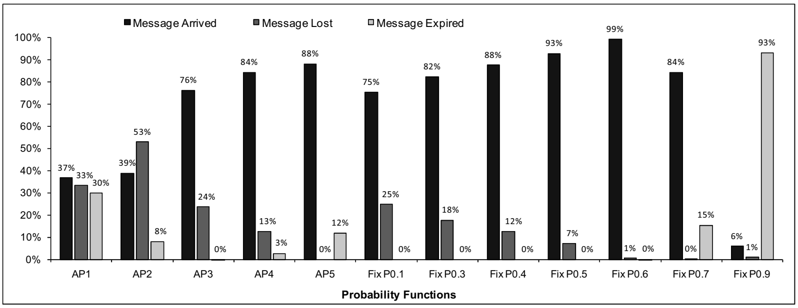


Fig. 2: The comparison of ratio message arrived target, message lost, and message expired

Fig. 3 and Fig. 4 analyze the number of messages reached their targets during simulation time. Both results of Fix-P0.9 show very low routing time and delay time because the number of messages could reach their targets in 6%. Fig. 3 presents the average of routing time compared to the average of shortest paths. Although the AP_θ^5 performs effective by reaching their target with high success; it surprisingly has very high routing time, 200 times compared to the shortest route which is caused by long routes from buffer usage consideration. The AP_θ^3 shows the best routing time among adaptive probabilities.

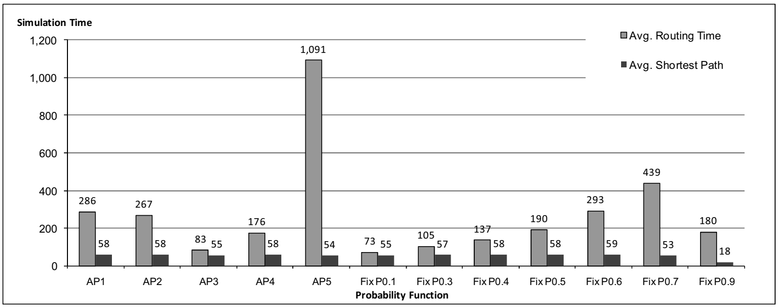


Fig. 3: The average of routing time compare to average of shortest path

Fig. 4 presents the average of delay time which summarized from waiting time due to high buffer queue. Almost adaptive probabilities have low delay time, and lower than all constant probabilities, except AP_θ^3 which similar to Fix-P0.5. Especially AP_θ^5 has the lowest delay time, further it has a high number of messages reaching their target.

The next diagram, Fig. 5, presents the amount of high buffer usage nodes in the community when the fraction of buffer usage is over 70%. The adaptive probability demonstrated remarkably results. The AP_θ^5 shows excellent; there is no node has higher level of buffer queue than 70%, and the buffers of three nodes are filled to 70% only. In contrast, AP_θ^1 and AP_θ^2 have many high buffer usage nodes; furthermore, they are higher than all constant probabilities.

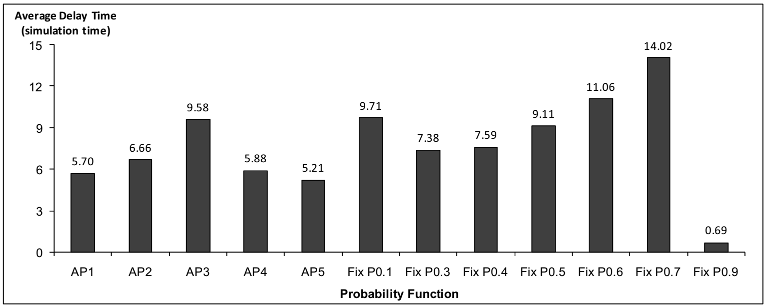


Fig. 4: The average of delay time

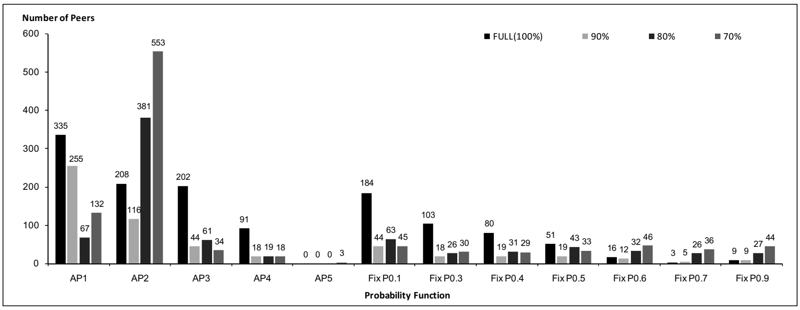
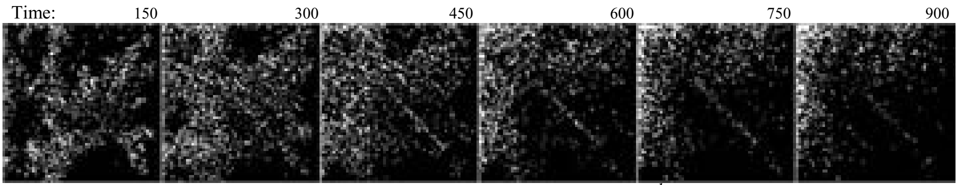


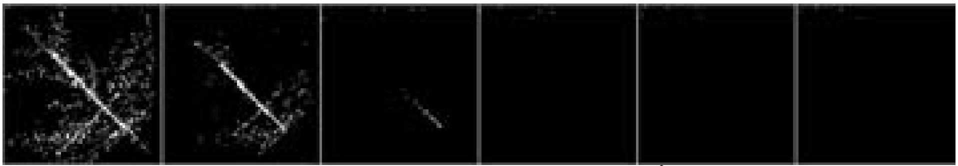
Fig. 5: The summary of number of high buffer usage nodes (70%up)

From these simulation results, it is clear that there is no probability that shows outstanding in every simulation scenarios and all performance metrics. A constant probability of 0.6 is the best according to the number of message reaching their target but it takes high routing time and high delay time. The number of messages reaching their target with constant probability of 0.5 is worse but routing time and delay time is better compared to the simulation with probability of 0.6. The results of adaptive probabilities perform better than global constant probabilities in balanced resource utilization. The AP_θ^5 shows good results; no high buffer usage node and low waiting time, however it takes very long routing time. The AP_θ^4 has similar behavior to the fixed probabilities of 0.4 and 0.5 but the adaptive one has lower delay time.

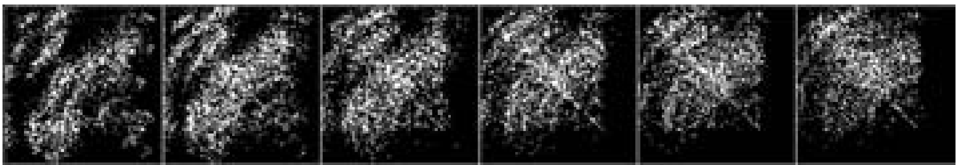
In Fig. 6, the buffer utilization status of the community (100x100) is captured for presenting the algorithm's performance. The sequence of picture is read from left to right. The application froze the buffer usage status at the simulation time-steps 150, 300, 450, 600, 750 and 900. The 50 source nodes are randomly distributed in the network. The four target locations are close to each other in the right-down corner. The density of the color presents buffer level of node. The higher buffer usage levels are shown as darker colors. The probability of AP_θ^1 decreases when the current node is closed to the target but its probability is always 1 when the current node is in an indirect route. In Fig. 6(a), messages are distributed over the network when simulation started. After that, messages between source and target could reach their target, but when messages are forwarded more indirect way then many grey spots on the top-left of the picture are shown.



(a) Adaptive probability function AP_θ^{1}



(b) Adaptive probability function AP_θ^{3}



(c) Adaptive probability function AP_θ^{5}

Fig. 6: The buffer status diagrams of a community 10,000 peers in 2-dimensions (100x100)

In contrast, the AP_θ^{3} probability range is lower. Then almost messages are forwarded with shortest policy. They could reach their target quickly. Hence, diagrams at time 150 and 300 on Fig. 6(b) have dark grey lines that represent high congestion nodes, and from time 450, there is no message left. Lastly, the AP_θ^{5} which has two functions in different criteria. The diagram, Fig. 6(c) has no dark grey nodes but there are many light grey nodes spreading over the network. It confirms the simulation result of AP_θ^{5} that has no high buffer usage.

5 Conclusion and Future Work

In this paper we introduced the adaptive probabilities using thermal field approach considering relative remaining distance. The experiments run with a powerful simulation tool, P2PNetSim. The test results proof that the thermal field algorithm enabled to find an appropriate path, and react to high buffer usage situations. But with differences performance among probabilities of using thermal field algorithm can be understood on the basis of the different degree of adaptively which the different flexibility respond to distance changing in time.

In future work, more constraints, such as bandwidth will be considered for improving quality of service routing. In addition, multi-criteria have concurrently to be considered to provide more efficient global routing optimization. Finally, the enhancement of routing algorithms will be studied by learning process.

References

[Ab07] Abraham, A.; Yue, B.; Xian, C.; Liu, H.; Pant, M.: Multi-objective Peer-to-Peer Neighbor-Selection Strategy Using Genetic Algorithm: LNCS 4873, 2007; S. 443-451.

[BSU09] Berg, D.; Sukjit, P.; Unger, H.: Grid Generation in Decentralized System, 2009.

[CL92] Cristopher, J.G.; Lionel, M.N.: Adaptive Routing in Mesh-Connected Networks: Proc. 12th International Conference on Distributed Computing Systems, 1992; S.12-19.

[Co06] Coltzau, H.: Specification and Implementation of Parallel P2P Network Simulation Environment: Diploma Thesis, University of Rostock, 2006.

[JVM95] Jatin, H.U.; Varavithya, V.; Mohapatra, P.: Efficient and Balanced Adaptive Routing in Two-Dimensional Meshes: In International Symposium on High Performance Computer Architecture, 1995; S. 112-121.

[Kl00] Kleinberg, J.: The small-world phenomenon: An algorithmic perspective: Proc. 32nd ACM Symposium on Theory of Computing, 2000.

[Lu04] Lua, E.K.; Crowcroft, J.; Pias, M.; Scharma, R.; Lim, S.: A Survey and Comparison of Peer-to-Peer Overlay Network Schemes: IEEE Communications Survey and Tutorial, March 2004.

[LU09] Lertsuwanakul, L.; Unger, H.: A Thermal Field Approach in A Mesh Overlay Network: 2009.

[LW04] Lee, A.; Ward, P.A.S.: A Study of Routing Algorithms in Wireless Mesh Networks: Australian Telecommunication Networks and Applications Conference, December 2004.

[Me04] Mello, A.V.; Ost, L.C.; Moraes F.G.; Calazans N.L.: Evaluation of Routing Algorithms on Mesh Based NoCs: Technical Report Series No.040, May 2004.

[RR91] Rajasekaran, S.; Raghavachari, M.: Optimal Randomized Algorithms for Multipacket and Wormhole Routing on the Mesh: Technical Report, University of Pensylvania, 1991.

[UW04] Unger, H.; Wulff, M.: Search in Communities: An Approach Derived from the Physic Analogue of Thermal Fields: Proc. the ISSADS 2004, LNCS 3061, Guadalajara, Mexico, 2004.

[XG07] Xu, M.; Guan, J.: Routing Based Load Balancing for Unstructured P2P Networks: FGCN-Future Generation Communication and Networking (FGCN 2007) - Volume 1, 2007; S. 332-337.