Fuzzy Logic Based Routing in Grid Overlay Network

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Abstract: With the aim to improve the quality of service of the modern distributed application, we propose a multi-criteria routing algorithm running in a mesh structured overlay network. Using a grid pattern can improve routing remarkably, since it provides alternative and partly disjunctive paths of equal length as well as the ability to measure distances between nodes in the overlay network. A Thermal Field approach is used to represent buffer stages on the nodes. The decision-making algorithms use fuzzy logic techniques to select the optimal path considering multiple constraints. The proposed algorithm is evaluated using P2PNetSim, a network simulation tool. The approach is compared to Shortest Path routing and probability functions using deterministic or adaptive approach. The result of routing with fuzzy logic shows superior routing performance than others both in delivery ratio and routing time.

1 Introduction

Quality of Service Routing (QoSR) is a key function for the transmission and distribution of digitized information across networks. It has two main objectives; finding routes that satisfy the QoSR constraints and making efficient resource utilization. Unfortunately, several factors can cause poor performance. So many problems still exist such as data loss because of overloaded incoming and outgoing message buffers, packet delay or expiry when residing in large queue or when using unsuitable routes. The complexity in QoS routing comes from multiple criteria, which often make the routing problem intractable. Typical criteria are node buffer capacities, residual link capacities, and number of hops on the path. Many routing algorithms [GRS05] have been developed in this research area. Expert systems, swarm intelligent systems, artificial neural networks, and fuzzy logic are applied for multi-constraint decision making. Many approaches focus on bandwidth and throughput optimizations.

We considered buffer utilization for improving robustness and to implement an efficient load balancing that is only based on local knowledge of the nodes involved. A fuzzy system was chosen because it provides a mathematical model for dealing with imprecision and uncertainty as given in common traffic situations in today's communication networks.

The overlay network approaches [Lu04] aim to support various features such as robust routing architectures, efficient searching and routing, load-balancing, distributed implementation of trust and authentication, and redundant storage, emerged in Peer-to-Peer (P2P) network. Structured P2P networks, such as CAN, Chord, and Pastry, provide Distributed Hash Tables (DHT) to identify relationships among nodes and files for searching and routing control. Whereas unstructured networks, ad-hoc systems, organize peers in a random graph and use flooding or random search on the graph to find the desired contents. In comparison, structured P2P networks can efficiently locate rare data since the key-based routing in scalable, but they incur significantly higher overhead for popular content.

The grid pattern with coordinate system provides many benefits for the routing process, because many paths with the same hop-count exist between two peers and they enable each peer to predict the shortest route without prior communication. Grid can be used to provide content-based coordinate systems generated from the distributed system's contents. The generated map can be changed dynamically according to overlaying application's requirements. The distance between peers is measured in Euclidean space. In [Be07] proposes routing in a mesh-like structure using the EPC code to establish an address space. Moreover, other applications such as Network Virtual Environments and Data mining application could be able to apply our adaptive routing approach on their content-grid structure.

The proposed algorithm takes the distance from the current node to the destination into account as well as the buffer usage level of each node's direct neighbors. The distance is measured by Euclidean space. To propagate the buffer levels in a node's neighborhood, a thermal-field-based approach is used. The locally executed decision-making process is based on fuzzy logic.

The rest of this paper is organized as follows: Section 2 provides related literature briefly and extensively description of classical routing methods on meshes, thermal field approaches, and fuzzy systems. Section 3 introduces our routing strategy considering multiple factors using fuzzy logic. Section 4 describes the simulation environment in P2PNetSim simulation tool, as well as the results and discussions. Finally, Section 5 concludes the paper and gives an outlook for future research.

2 Related Work

Many adaptive routing algorithms considering multi-constraint to improve QoSR have been introduced in before. Zhang and Zhu [ZZ05] introduced an algorithm considering number of hops and available buffer-capacities in general communication networks. FLAR [MTR07] and FACO [GDT09] describe routing algorithms applying ant colony systems and fuzzy logic to consider multiple constraints in Mobile Ad Hoc Network (MANET). FLAR considered route utilization and route delay but FACO considered buffer occupancy, remaining battery power and signal scalability. A fuzzy mixed metric approach, introduced in [US08], is used to make optimal routing decisions in packet switching network by considering one or multiple QoS factors.

The introduced routing approach is run on a mesh overlay network, in which the distance is measured by coordinate system. One of the well-known routing algorithms in grid-like networks was introduced by Jon Kleinberg [Kl00]. He introduced a decentralized algorithm in grid, where he added long-range links to forward messages from any source node to target within only $O(\log^2 n)$ delivery time complexity. Meanwhile the probability proportional of long-range random links between nodes v and w is $d(v,w)^{-2}$. Some networks with coordinate systems are built in the lower layer of the network stack, e.g. [DGK09], but also approaches for building grid in the application layer exist, as in [BSU09, Be07]. In [BSU09], a grid structure is generated on top of a large-scale decentralized network. Their logical grid is built without centralized control and global instances; only local knowledge of each node is needed.

2.1 Routing in Grid-like Structure

Grid or mesh patterns have been used in many areas of communication networks. The advantage of mesh structures is their reliability and inherent redundancy of the connection. Many applications using grid structure are implemented in packet/circuit switching both in wireless networks and wired networks, vehicle problems, and software interaction [CL92, JVM95, LW04, RR91]. Some examples of routing algorithms in mesh-connected topologies are presented in [Me04]. A deterministic routing method in grid is called “XY” routing algorithm where packets are routed along X direction until reaching the X value of the target and then route the packet in Y direction to the target. This kind of routing can be refined, named the partial-adaptive routing algorithms; “West-First”, “North-Last”, and “Negative-First” approaches. These methods change packet routes dynamically by using a function that reacts immediately on network traffic, but in some specific conditions they use the deterministic ways.

All these classical routing methods have in common that they choose between multiple paths having the same hop count. The source node wants to send information to the target node. Then the best path depending on the algorithm is selected. The chance to find low QoS relies on the path selection function. If the selected route has many overloaded peers, then the delay time increases or the packet losses occur.

2.2 Thermal Field

Unger and Wulff [UW04] were introduced the Thermal Field approach which is used for searching nodes in P2P networks that keep the desired data; like 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. 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. 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 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 neighbour.

However, there is a difference from nature that the virtual community is able to memorize temperatures from latest access of each neighbour. Consequently, when a message requests for special information, it can be transferred to the "hottest" neighbour that is kept in memory.

The Thermal Field approach is also used in routing in overlay network representing the level of buffer usage. In [LU09a], route decision is chosen either an adaptive or a directed route depending on a global predefined probability. This decision immediately reflects the buffer level of the considered node's neighbour at decision time. And in [LU09b], five adaptive probability functions of relative remaining distance were used to further improve the routing decision. It extended prior algorithm to avoid the global parameters. These approaches can gather remarkable advantages from the underlying grid-like structure, which offers a lot of alternative routing paths for a single message.

2.3 Fuzzy Logic

Fuzzy Logic introduced by Zadeh [Za65] allows a computer to model the same way that people do, not always precise. People think and reason using linguistic terms such as "hot" and "fast", rather than in precise numerical terms "90 degrees" and "200 km/hours" respectively. The fuzzy set theory models the interpretation of imprecise and incomplete sensory information as perceived by human brain. Thus, it represents and numerically manipulates such linguistic information in a natural way via membership functions and fuzzy rules. Some advantages of fuzzy logic are conceptually easy to understand, flexible, and tolerant of imprecise data. It can model nonlinear functions of complexity, and also can be built on top of the experience of experts.

A key feature of Fuzzy logic is to handle uncertainties and non-linearity, existing in physical systems, similarly to the reasoning conducted by human beings, which makes it very attractive for decision making systems. A fuzzy logic system comprises basically three elements: (i) Fuzzification, (ii) Knowledge base (rule and function), and (iii) Defuzzification. In Fig. 1 shows the generalized blog diagram of fuzzy system.

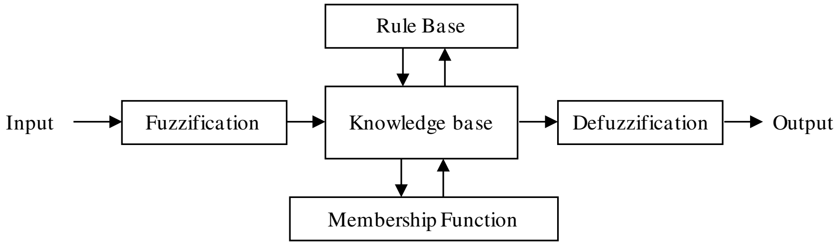

Fig. 1: A block diagram of a generalized fuzzy system

The function of the fuzzification is to determine the degree of membership to a crisp input in a fuzzy set. The fuzzy rule base is used to present the fuzzy relationship between input-output fuzzy variables. The output of the fuzzy rule base is determined based on the degree of membership specified by the fuzzifier. The defuzzification is used to convert outputs to the fuzzy rule base into crisp values.

In Section 2, we presented the classical routing in mesh, the thermal field approach and fundamental fuzzy logic technique. The next section, we will explain how the fuzzy logic works to find an optimal routes by considering relative distances in grid and buffer usage level.

3 Algorithms

In this section we describe our algorithm in details. The route decision process is constructed with the communication model transmitted temperature value by agents and use fuzzy logic to find the best path. Our approach considers decision position in terms of distance relationship and buffer usage status concurrently. The distance between nodes is measured by Euclidean distance from coordinate of grid. And the thermal field represented buffer usage level is used for communicating buffer information over the network. So that, every node has to keep its neighbours' temperatures and coordinate ID. The lower temperatures represent more available resources to handle new data. In the route decision process, the distance of original to target node, current to target peer, and neighbours to target location are measured.

3.1 Measuring the Temperature

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.

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

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 neighbours $N(c)$ where messages can be forwarded to and i is a number of neighbour, then $N_i \in N(c), 1 \leq i \leq 4$. There are three possibilities to update a neighbours' 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 neighbour N_i to current node.

1. If node c receives a packet or an acknowledgment from neighbour 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 neighbour 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.

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

Next topic, we introduce how fuzzy logic system works when knows distance and temperature of its neighbours.

3.2 Fuzzy Logic

The inputs to the fuzzy controller to be designed for routing are: (i) buffer usage status, (ii) distance, and (iii) neighbour type. These three selection parameters make the route reflect the network status and the nodes' ability to reliability delivery network packet. The distance is defined current packet-holder position compares to source and target. It is calculated by equation (1), and neighbour type is in equation (2):

$$Distance = \frac{\sqrt{(x_d - x_s)^2 + (y_d - y_s)^2}}{\sqrt{(x_d - x_c)^2 + (y_d - y_c)^2}} \tag{1}$$

$$Neighbor\ Type = \sqrt{(x_{Ni} - x_t)^2 + (y_{Ni} - y_t)^2} - \sqrt{(x_c - x_t)^2 + (y_c - y_t)^2} \tag{2}$$

Where (x_c,y_c) is current peer, (x_s,y_s) is source node, (x_d,y_d) is destination, and (x_{Ni},y_{Ni}) is neighbours i of current node. The steps involved in calculation of neighbour preference rate are elaborated in Fuzzy Interference System (FIS). The three input variables to be fuzzified are the thermal value (buffer usage status), the relative distance, and the neighbour type. The terms "Empty", "Few", "Half", "Almost", and "Full" are used to describe the temperature field. "VeryClose", "Close", "StartPoint", "Far", and "VeryFar" are termed to explain the relation of distance and "Closer" and "Farer" are described neighbour types. In Fig. 2 shows the membership functions of input variable.

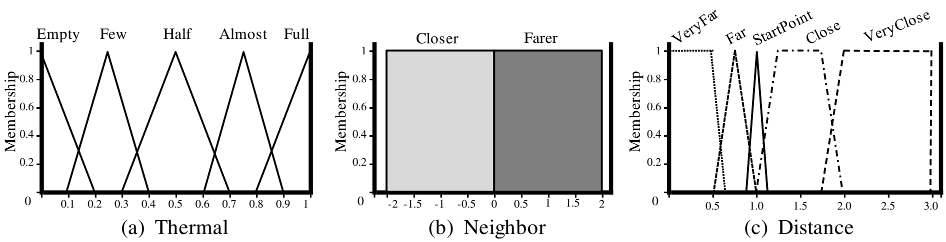

Fig. 2: Fuzzy Membership function of input variable

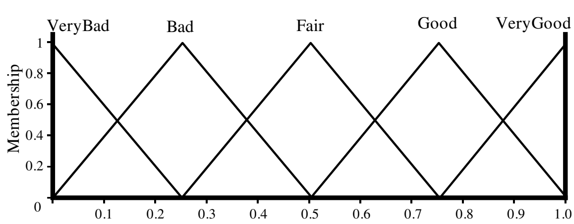

Fig. 3: Fuzzy Membership function of Neighbour Rate

Fig. 3 shows the membership functions of output, neighbour rate. We define nine terms for the values of neighbour rate from lowest to highest as “VeryBad”, “Bad”, “Fair”, “Good”, and “VeryGood”. The rules of the FIS are designed for an optimal path. Table 1 shows rule base for the FIS.

Neighbor Rate		Neighbor = Closer					Neighbor = Farer				
		Thermal					Thermal				
		Empty	Few	Half	Almost	Full	Empty	Few	Half	Almost	Full
Distance	VeryClose	VeryGood	VeryGood	Good	Fair	Bad	Good	Good	Fair	Bad	VeryBad
	Close	VeryGood	VeryGood	Good	Fair	Bad	Good	Good	Fair	Bad	VeryBad
	StartPoint	VeryGood	VeryGood	Good	Fair	Bad	Good	Good	Fair	Bad	VeryBad
	Far	VeryGood	Good	Fair	Bad	Bad	Fair	Fair	Bad	VeryBad	VeryBad
	VeryFar	VeryGood	Good	Fair	Bad	Bad	Fair	Bad	VeryBad	VeryBad	VeryBad

Table 1: Fuzzy Rule Base

There are 37 rules defined for this fuzzy system. The examples are showed in the following:

R1: IF thermal IS Empty AND neighbour IS Closer THEN neighbour_rate IS VeryGood;
R2: IF thermal IS Full AND neighbour IS Farer THEN neighbour_rate IS VeryBad;
...
R37: IF thermal IS Almost AND distance IS VeryFar AND neighbour IS Farer THEN neighbour_rate IS VeryBad;

The defuzzification is the process of conversion of fuzzy output set into a single number. The method “Center of Gravity” (COG) is chosen as show in equation (3)

$$Neighbor\ Rate = \frac{\sum_{i=1}^{n} X_i \cdot \mu(x_i)}{\sum_{i=1}^{N} \mu(x_i)} \quad (3)$$

Where x_i is the element and $\mu(x_i)$ is its membership function. COG method is the most widely defuzzification strategy, which is reminiscent of the calculation of the expected value of probability distributions.

The details proposed algorithm is explained. Next in Section 4, we will present some experimental results. The outcomes compare to shortest path method and adaptive probability functions to use thermal field.

4 Experimental consideration

We conducted experiments to evaluate the proposed protocol, and compare to the shortest path method and thermal approach by fixed functions algorithm. Since our approach run in decentralized network, each node knows only its neighbourhood peers. The route decision is made step by step when it hold message. The shortest path method finds the fastest way in terms of number of hop-count then the message is forwarded to the shortest neighbour to destination.

Other constraints aren't considered. On another factor, the thermal approach is used for considering buffer usage level [LU09b]. The functions for probability to select either low buffer route or shortest way are predefined. In this paper, we selected the two different formulas in comparison.

4.1 Environment Setting

The experiment was simulated using P2PnetSim, a network simulation environment. The tool is powerful and flexible in simulating, modeling and analyzing any kind of networks. Peers are configured collectively and individually using XML files for network setup, and Peer behaviors are implemented in the Java programming language. In our experiments, the network is organized into a grid structure with 1,024 nodes in two dimensions (32x32). 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 Power-Law distribution. There are two types of packets, data and acknowledgements. The acknowledgment is prioritized. Otherwise, the system handles the packets First-In-First-Out.

To generate traffic, the simulation defines different throughputs for nodes in terms of buffer sizes and outgoing bandwidths. In the trial, the 338 source nodes are uniformed randomly selected together with predefined target randomly in a specific area. Source nodes send a message to its target with probability 0.2. They generate a message in every simulation time until total messages are 50,000 packets. In order to evaluate algorithm performances messages success delivery ratio, message loss ratio, and message expired ratio are measured. Besides, a node (31, 28) is set to assess routing time. It generated a packet every simulation time until 500 messages sent to target (0, 0). The 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.

4.2. Results and Discussion

The experiments report in this section compares to shortest path methods and thermal approach with two probability functions (4 & 5) as introduced in [LU09b]. Packet delivery ratio is important as it describes the successful rate that will be seen by the transport protocol, which in turn affects the routing quality that the network can support.

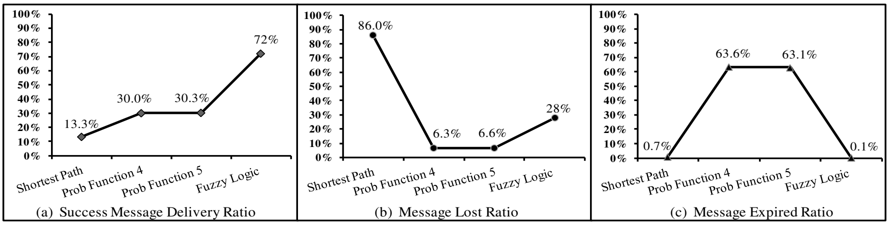

Fig. 4: Packet Delivery Ratio

Fig. 4(a) presents that packet success delivery ratio is the highest for routing with fuzzy logic, which is due to its ability to select a least congested routes thus having the lowest amount of loss as shows in Fig. 4(b). Moreover, a very few message expired ratio in Fig. 4(c) is also lowest which points that proposed algorithm is able to avoid very long indirect route and/or long queue in buffer peers.

Fig. 5 presents an example routing performance of evaluation node (31,28) which sent packets to its target peer (0,0). The average routing time is the average time to deliver a packet from launched at source to reached target, and it includes all possible delays such as waiting in buffer queue. And the average number of hop-count is the average number of peer that packets are passed during transmission. The minimum hop-count from node (31,28) to node (0,0) is 59 steps in grid. The shortest path method obviously shows every message transport to destination with a number of hop-count, 59 times. However, average routing time is quite high due to waiting time in long queue buffer nodes. And due to shortest path protocol aim to transmit in the fastest way, packet lost ratio as in Fig. 4(b) is highest. On the other hand, the thermal approach with predefined probability functions to select either available buffer path or shortest route shows value of average routing time and average number of hop-count in similar that means they are a good approach in terms of avoid long queue of busy nodes. But packet delivery ratios in Fig. 4 reveal that many long indirect routes are chosen to avoid congestion nodes made high percentage of expired packet. The best results are from multi-criteria using fuzzy logic. It balances avoidance of indirect route and escape from busy nodes.

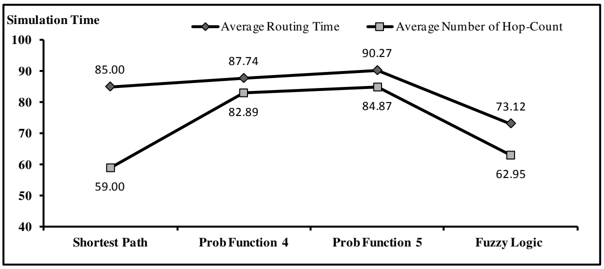

Fig. 5: The average routing time

5 Conclusion and Future Work

In this paper we introduced a multi-criteria routing algorithm using fuzzy logic system. Our method runs in grid-like structured overlay network then only local information is used to find an optimal path. The buffer usage status is applied by thermal approach. And the relative distance among peers are beneficial from coordinate in grid structure. Both criteria are taken into account to find the best path and balance resource utilization by fuzzy logic. The experiment results proof that the introduced algorithm enabled to find an appropriate path, and react to high buffer usage situations. In future work, more constraints, such as bandwidth will be considered for improving quality of service routing. In addition, the enhancement of routing algorithms will be studied by learning process.

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