Fuzzy Optimized Metric for Adaptive Network Routing

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Abstract

In this paper, a fuzzy inference rule base is implemented to generate the fuzzy cost of each candidate path to be used in routing the incoming calls. This fuzzy cost is based on the crisp values of the different metrics; a fuzzy membership function is defined. The parameters of these membership functions reflect dynamically the requirement of the incoming traffic service as well as the current state of the links in the path. And this paper investigates how three metrics, the mean link bandwidth, queue utilization and the mean link delay, can be related using a simple fuzzy logic algorithm to produce a optimized cost of the link for a certain interval that is more 'precise' than either of the single metric, to solve routing problem .

Keywords: Adaptive Routing, Fuzzy logic, Short Path Routing Control, Link Cost, Network Routing.

1. INTRODUCTION

Today network routing algorithms used to calculate least cost (shortest) paths between nodes. The cost of a path is the sum of the cost of all links on that path. The cost of a link can be static (a function of the link) or dynamic (a function of the link and its dynamic state). The paths for routing that, using dynamic cost metrics can be recomputed based on prevailing traffic patterns to reduce congestion, packet delay, and packet drops[1].

To reflect the actual state of the link, the use of a single metric for adaptive routing is insufficient. As Known, there is a limitation on the accuracy of the link state information obtained by the routing protocol [2, 3], as the accuracy of the metric is usually predetermined by the network state update interval [4]. But better when two or more metrics can be associated to produce a single metric that can describe the state of the link more accurately.

In 1965 Zadeh initiated the fuzzy set theory [5, 6], for solving problems that are either difficult to tackle mathematically or when we need to improved performance, we can use Fuzzy logic. In communication systems there are Many design and control problems are indeed well suited for analysis using fuzzy logic.

In this paper, a fuzzy inference rule base is implemented to generate the fuzzy cost of each candidate path to be used in routing the incoming calls. This fuzzy cost is based on the crisp values of the different metrics, a fuzzy membership function is defined .The parameters of these membership functions reflect dynamically the requirement of the incoming traffic service as well as the current state of the links in the path .
The remainder of the paper is organized as follows: Section 2 presents network model and problem formulation. Key ideas of our approach are presented in Section 3. Section Simulation results are shown in Section 4. Finally, Section 5 concludes the paper.

2. NETWORK MODEL AND PROBLEM FORMULATION

A network can be modeled as a graph G =. *V, E*. Where (*V*) is the set of nodes represent switches, routers and hosts. Edges (*E*) represent a set of communication links. That is, for node i and j in V, the link $l_{i,j}$ is in E if i and j are directly connected in G. Each link $l_{i,j}$ in E is associated with a primary cost parameter In our discussion, we assume that each link $l_{i,j}$ is associated with a link metric vector $W_{i,j}$ = { W_1, W_2, $W_{3\}}$, in which W_i is an individual link metric.

2.1 Link Metrics

In shortest path routing algorithms link costs can be assigned dynamically and statically. The simplest of all the metrics is the hop count. Delay, bandwidth of the link, Queue size, propagation delay and some of the other metrics The selection of the routing metrics substantially affects the performance parameters of the routing algorithms. The most common metrics are the bandwidth, packet delay, queuing delay, and packet loss [7].

The packet delay, also known as latency, consists of three different types, namely, serialization delay, propagation delay, and switching delay. Serialization delay, also called transmission delay, is the time it takes a device to synchronize a packet on a specified output rate. This transmission delay is a function of the bandwidth and the packet size[8].

$$t_{tra} = L_p / B \tag{1}$$

Where ttra represent link transmission packet delay, Lp packet length in bits and B the bandwidth in bit/sec.

Propagation delay is the time it takes a bit to travel from a transmitter to a receiver. Physics set upper limits on the speed of such a bit, making at best a fraction of the speed of light. Hence, propagation delay is a function of the distance traveled and the link medium.

$$t_{pro} = Bd/V \tag{2}$$

Where d represents link length and V is the light velocity.

Switching delay is the time lag between receiving a packet and starting to retransmit it. The switching delay is a function of the device speed which is small and can be neglect.
Transmission delay of the link is the major routing link metric. A useful way of looking at this is to consider link length as compared to the typical frame transmitted. The length of the link, expressed in bite, compared to the length of the typical frame is usually denoted by W_1:

$$W_1 = \text{(length of link in bits) / (length of frame)} \tag{3}$$

Some manipulation shows that [8,9] :

$$W_1 = \text{propagation time / transition time} \tag{4}$$

Typical values of delay factor W_1 range from about 0.01 to 0.1 for LNDs and 0.01 to over 1 for other.

In addition to those three types of delay, other delays also contribute to the overall performance of the network.. When the network is congested, queues will build up at the routers and start affecting the end-to-end delays [10]. Queuing delay may be negligible when the network is fast and not experiencing congestion. However, when the network is congested, the queuing delay grows and becomes significant. The number of packets in a queue is a random variable and its distribution depends on γ, the ratio of arrival rate to service rate. The probability p of having n packets in the queue is computed as follows:

$$P(n) = (1 - \gamma) \times \gamma^n \tag{5}$$

The queuing utilization w_1 is the ratio of the queue size to queue capacity Q. Queue size defines the buffer length at the node and it refers to the number of packets waiting to get processed. The queue size is a function of the number of packets n currently in the queue and packets length Lp per second. The queuing utilization W_2 can be computed as follows:

$$W_2 = n\, L_p / Q \qquad (6)$$

The values of w2 thus range from 0 to 1.

The term bandwidth defines the transmission capacity of an electronic line [11]. Theoretically, it describes the range of possible transmission rates, or frequencies [12]. The significance of a link bandwidth is that it determines the link capacity, which is the maximum information rate that can be transmitted [13].
Each link in the network has residual bandwidth property. The residual bandwidth R is defined as the difference between the link bandwidth B and the sum of the bandwidths of all the paths already assigned to that link[16]. But to make the analysis completely independent of the actual link rat, the residual bandwidth is expressed in a dimensionless normalized form:

$$W_3 = R / B \qquad (7)$$

The value of W_3 also ranged from 0 to 1.

To calculate least cost paths between nodes, we used the network routing algorithms. The cost of a path is the sum of the cost of all links on that path. The use of a single metric for adaptive routing is insufficient to reflect the actual state of the link. As known, for the link state information obtained by the routing protocol there is a limitation on the accuracy. But to describe the state of the link more accurately, if the above three metrics can be associated to produce a single metric.

2.2 Optimized Metric
Metrics combination reduces the complexity of the routing algorithm problem by combining more metrics in a single metric and then using a traditional shortest-path algorithm to compute the path that minimizes the resulting metric. In this work we combine the three above metrics in single optimal one [17].

Every link has a state measured by the difference metrics of concern. In Figure 1, the link state is a triple consisting of delay factor, Queue utilization and residual bandwidth. Every node also has a state.

The node state can be measured by combined into the state of the adjacent links or, independently in this paper,. For the latter case, the residual bandwidth is the minimal of the link bandwidth; the delay of a link consists of the link transmission delay and the queuing delay at the node; the cost of a link is determined by the total resource consumption at the link and the node.

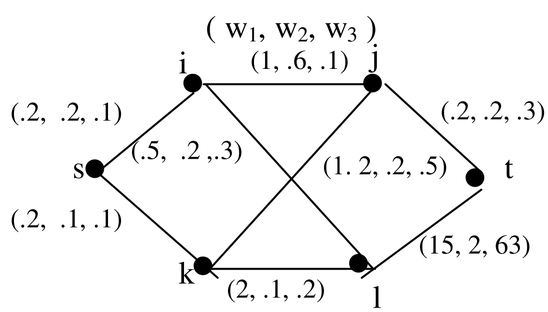

FIGURE 1: Network state

As we will shown later link metrics (bandwidth, delay ,and queue utilization) will be consider as input to fuzzy system and the output will be as metric which will represent optimized metric (link cost).

3. THE FUZZY APPROACH DESCRIPTION

A fuzzy system [14, 15] is a rule-based system. The aim of a fuzzy system is to substitute for or replace a skilled human operator with a fuzzy rule-based system. Based on the current state of a system, and to guarantee that it is optimal in some certain senses, an inference engine equipped with a fuzzy rule base determines an on-line decision to adjust the system.

The design process of a fuzzy control system consists of a the following steps. The first step is to define the input variables and the control variables. The input variables may be fuzzy or crisp. Each variable must be quantified; and, the variable temperature may be quantified as cold, warm, or hot.

Each quantification of the variable is assigned a membership function. A for each quantification of the input and control variables, must be design a fuzzy rules base. These rules base determine what control actions take place under what input conditions. The rules are written in an if-then format. To determine the fuzzy control action, an approximate reasoning method must be used. The approximate reasoning method provides a means of activating the fuzzy rule base. A to evaluate the individual if-then rules in the rule base, implication formula is used, but to aggregate the rule results to yield a fuzzy output set, we use A composition .

The structure of fuzzy system translates inferring stage of metrics optimization processing knowledge, and combines fuzzy rules with a inference mechanism into a unified model. In this paper, two sets of rules were used: Fuzzy Rules base 1 and base 2, relationships between these two rules base and all variable used in fuzzy system can be represented best by hierarchical structure shown in Figure 2.

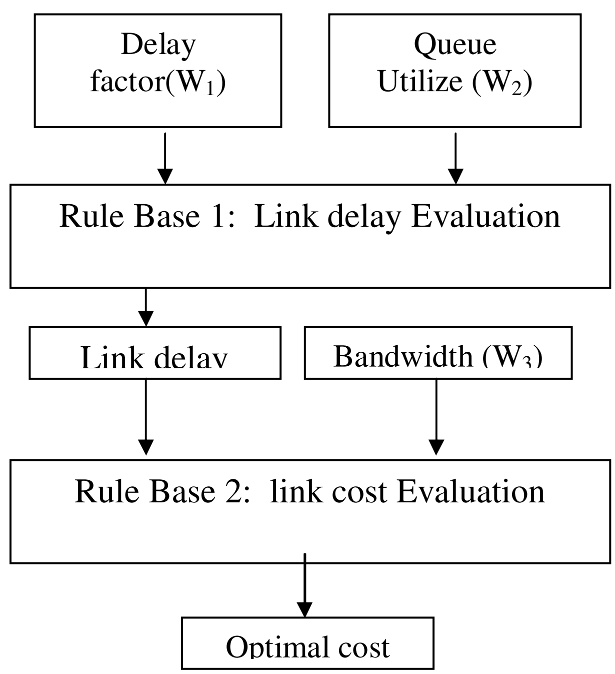

FIGURE 2: Hierarchical structure fuzzy system

3.1 Membership Functions

The implication formula provides a membership function that measures the degree of truth of the implication relation (i.e., the “if then” rule) between the input and output variables. One frequently used implication formula is that of Mamdani. Let a fuzzy rule be stated as follows:
if x is A, then y is N.
The implication formulas of Mamdani are as follows:

$$\mu A \rightarrow N\,(x,y) = \mu A(x) \wedge \mu N(y) \quad (8)$$

Where $\mu A(x)$ is the membership of x in A, $\mu N(y)$ is the membership of y in N, $\mu A \rightarrow N\,(x,y)$ is the membership of the implication relation between x and y, and $\wedge$ is the minimum operator.
In this paper, the membership functions for the fuzzy sets are chosen to be triangular and trapezoidal fuzzy numbers to express linguistic terms. To describe the fuzzy rules, we use L, M, H to indicate "Low", "Medium", and "High".

Trapezoidal membership functions were used for the linguistic variables that represent delay factor and queue utilization. The trapezoidal membership function is specified by low, medium and high as shown in Figure 3 and 4. The universes of discourse for the fuzzy delay factor were chosen [0, 10].

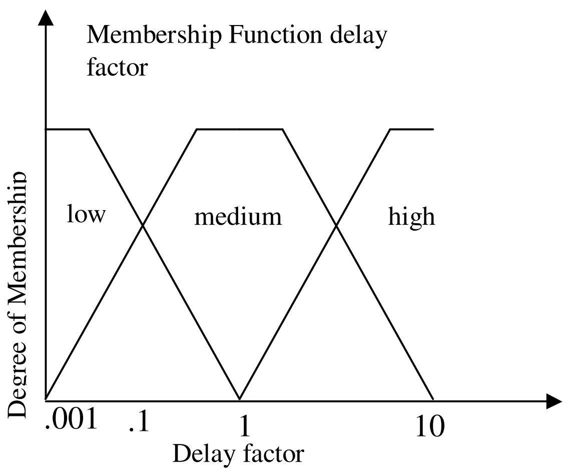

FIGURE 3: Link Delay membership function

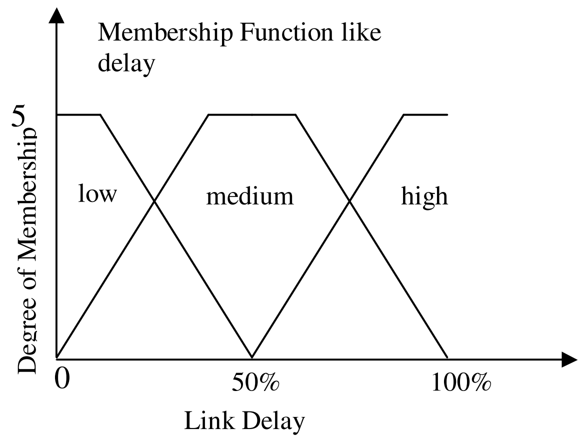

FIGURE 4: Queue utilization membership function

Triangular membership functions were used for the linguistic variables that represent link delay, bandwidth and link cost. The triangular membership function is specified as shown in Figure 5 and 6.

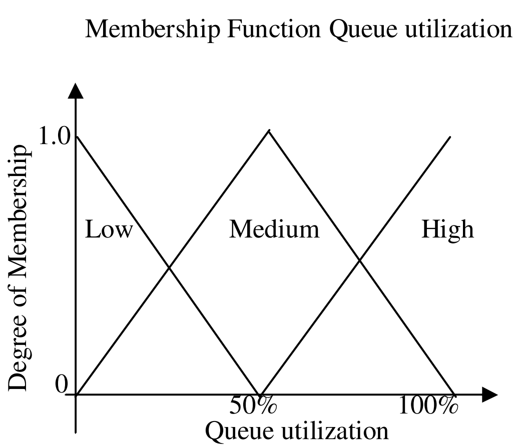

FIGURE 5: Queue utilization membership

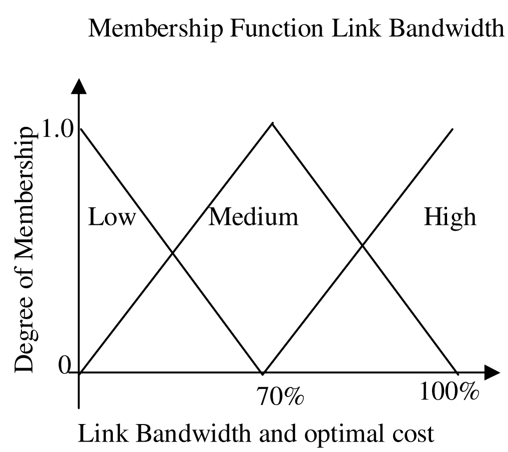

FIGURE 6: Bandwidth and Optimal cost membership

3.2 The Fuzzy Inference System

A fuzzy system is characterized by a set of linguistic statement based on expert knowledge. The expert knowledge is usually in the form of "if-then" rule, which are easily implemented by fuzzy condition statement in fuzzy logic. The collection of fuzzy control rules that are expressed as fuzzy inference system [7].

In this paper, two sets of rules were used: Fuzzy Rules Set 1 and Set 2, as summarized in the rule matrix on the tables 1 and 2 respectively. Table 1 illustrates the rule base 1 used in the fuzzy inference system. Expert knowledge was used in developing the rule base. While the delay factor and Q-utilization are represented in the X and Y-axis's respectively, the link delay fills the table.
The reason that the fuzzy rules in Set 1 below having a symmetrical output responses with respect to input conditions was simply for simplicity and was later used as a input variable for the Fuzzy Rules Set 2. The two input parameters, link delay and link bandwidth, for the Fuzzy Rules Set 2 were described in table 2. This gave a 3-by-3 matrix, with the columns representing "Low", "Medium" and "High" Link bandwidth, and the rows representing "Low", "Medium" and "High" link delay, as shown in table 2 below. The output parameter, namely the fuzzy metric, was described using 3 variables also: Low, Medium and High.

Q-utilization \ Delay factor	H	M	L
H	H	H	H
M	H	M	M
L	H	M	L

TABLE 1: Rule Base1.

Link Delay \ Link Bandwidth	L	M	H
L	L	M	H
M	M	M	H
H	M	H	H

TABLE 2: Rule Base1.

Using the rule-based structure of fuzzy logic, a series of IF X AND Y THEN Z rules were defined for the output response given the input conditions. With a 3-by-3 rule matrix as above, there were nine possible logical products (AND) output response conclusions:

The proposed approach is generic and should be easily modified to fit with different routing metrics. The fuzzy control method used is the one proposed by Momdani, which is the most widely used in fuzzy control [7]. Mamdani implication is used to represent the meaning of "if-then" rules. This kind of implication is most popular in the fuzzy control field because it is computationally simple and fits various practical applications.

A defuzzification method is then applied to the fuzzy control action to produce a crisp control action. One simple and frequently used defuzzification method is then applied to the fuzzy control action to produce a crisp control action. Center of Area Method (COA) is used as a defuxxification method to produce the crisp (nonfuzzy) cost output.

In the COA method, the weighted strengths of each output variable were multiplied by their respective output variable center points and summed. The area was then divided by the sum of the weighted member function strengths and the result was taken as the crisp output.

4. THE ROUTING MODEL

There are generally two kinds of fuzzy logic controllers. One is feedback controller, which is not suitable for the high performance communication networks. Another one, which is used in this paper, is shown in Figure 7. This control mechanism is different from the conventional feedback control and considered as an adaptive control.

To design the fuzzy controller, we need to explore the implicit and explicit relationships within the system and subsequently develop the optimal fuzzy control rules as well as the knowledge base.

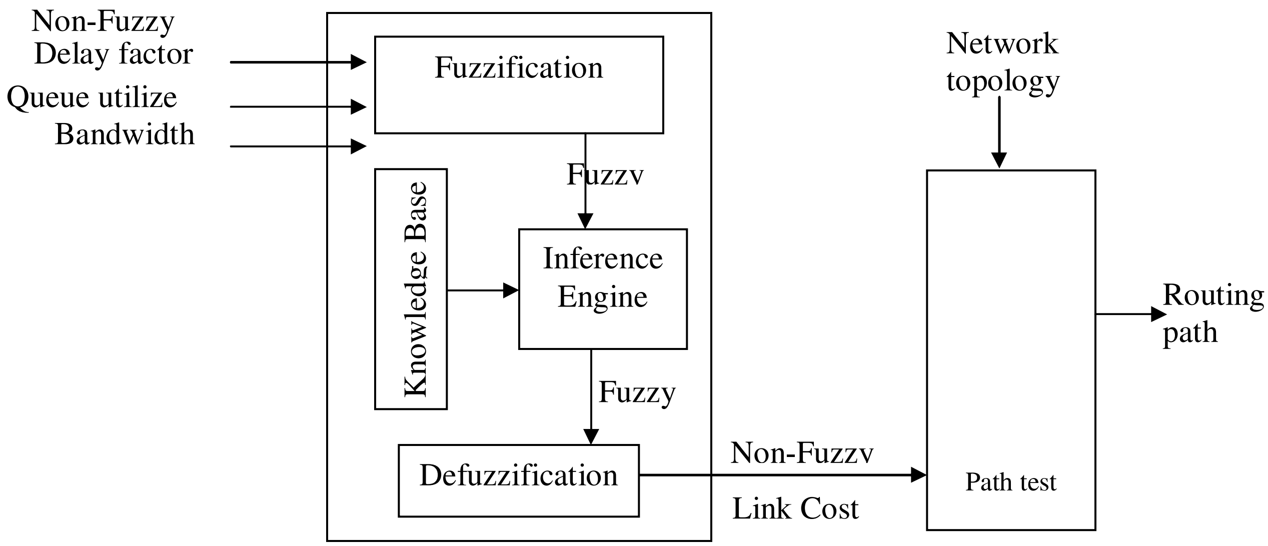

FIGURE 1: The fuzzy system

Figure 7 contains the different component of the routing system used to rout the incoming flows. This system is based on the fuzzy inference system discussed in previous section.
The process of applying the rules and membership function is a combination of four sub-processes: fuzzification, inference, composition and defuzzification.

5. APPLICATION RESULTS

The network model used for testing the fuzzy metrics is adapted from Balakrishnan et. al. [18], and it is shown in Figure 8.

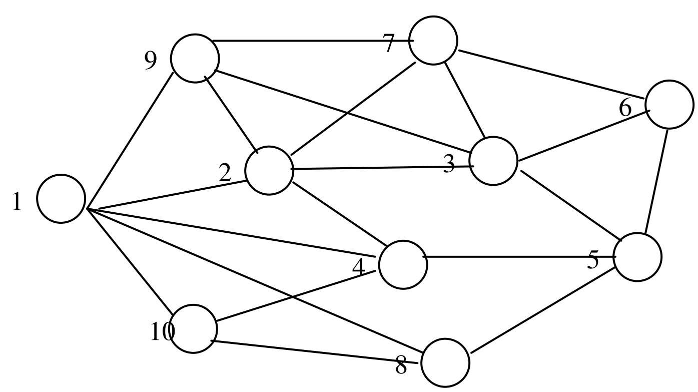

FIGURE 8: Experimental communication network topology [18]

For the sake of easy illustration, it is assumed that the links between the nodes are all with the same length. In this case the propagation delay of a traffic flow in the high performance communication is normally very small compared with its queuing delay at the switching nodes. Each node has incoming packet buffer with a maximum capacity of Q.

The proposed network was tested on various load conditions. The performance measure used to evaluate the proposed technique was optimal link cost. The existing metrics used for comparison are the delay factor, Q-utilization and the bandwidth. Tables 3 illustrate the optimal link cost for different metrics for network.

L_{ij}	W_1	W_2%	Link delay %	W_3%	Link cost %
1-2	.02	10	14	90	80
1-9	.1	20	22	80	78
1-10	.5	30	41	50	48
1-4	1	40	46	30	40
1-8	1.5	50	58	20	36
2-9	2	60	62	90	92
2-4	6	70	80	10	72
2-7	9	80	85	60	83
2-3	5.3	90	83	1	52
10-4	3.1	11.5	81	65	63
10-8	.9	25	78	40	41
7-3	.05	35	20	55	60
7-6	1	45	47	75	70
4-5	1.5	55	50	12	28
8-5	.3	65	47	18	30
3-7	4	75	88	95	100
3-6	1.9	.85	83	100	100
3-5	.75	.95	75	30	70
5-6	2	1	100	80	100
9-7	2.4	.2	65	90	78
9-3	6	5	70	38	68

TABLE 3: link cost for different metrics for Network.

6. CONCLUSIONS

Metrics in communication networks using a fuzzy system was proposed in this paper. The proposed fuzzy system showed better system performance and utilization of the network resources when compared to other metrics under various load conditions. Increased flexibility in the constraints that can be considered in the routing decision and the ease in considering multiple constraints are the benefits of such system. The design of a simple fuzzy optimal metric is presented and tested on an experimental network.

The results of this experiment prove that the proposed system can adapt the communication network over time to deal with changing conditions, and the systems are easy to construct.

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