Computer Network Routing Using Fuzzy Systems

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Abstract

The fuzzy logic presents widely conducing to solve the routing problem in the computer networks. It can be used to find fuzzy cost of links depending on several criteria. In this paper, two methods are proposed to solve this problem. The fuzzy systems are used to make routing decision, and to manage congestion control with solving of th-e routing problem. They have input variables and output variables, with linguistic values of triangular or trapezoidal membership functions. The proposed methods are applied for typical examples of computer networks. Results of these fuzzy systems assert their high achievement.

ايجـاد مسـار شبكة حاسبـات باستخـدام الانظمـة المضببـة

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المستخلص

المنطق المضبب قدم مساهمة واسعة لحل مسألة ايجاد مسار في شبكات الحاسبات. ممكن استخدامه لايجاد كلفة مضببة لروابط اعتمادا" على وسائل قياس متعدده. في هذا البحث، اقترحت طريقتين لحـل هـذه المسألة. الانظمة المضببة استخدمت لصنع قرار ايجاد مسار، ومعالجة مشكلة الاكتظاظ مع حل مسالة ايجـاد مسار . هذه الانظمة تمتلك متغيرات ادخال ومتغيرات اخراج ذات قيم لغوية لدوال عضوية مثلثيـة او شـبه المنحرف. الطرق المقترحة طبقت لأمثلة نموذجية لشبكات الحاسبات. نتائج هذه الانظمة المضـببة اكـدت على انجازيتها العالية.
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1. Introduction

In a communication network information is transferred from one node to another as data packets. Packet routing is a process of sending a packet from its source node (s) to its destination node (d). On its way, the packet spends some time waiting in the queues of intermediate nodes while they are busy processing the packets that came earlier. Thus the delivery time of the packet, defined as the time it takes for the packet to reach its destination, depends mainly on the total time it has to spend in the queues of the intermediate nodes. Normally, there are multiple routes that packet could take, which means that the choice of the route is crucial to the delivery time of the packet for any (source, destination) pair (S. Kumar and R. Miikkulainen 1998).

Successful operation of data communication network is critically dependent on the provision of an adequate routing algorithm. Routing algorithms are methods for finding the best way from a node s to another node d. This may be via a large number of other nodes or it may be in the next subnetwork. On a small, simple network the problem is almost trivial, statically allocating routes and defining them by hand, but when dealing with a huge internetwork such as the Internet this is not possible. It heavily interconnected network has many routes from one node to another, and these routes span many different types of link with different bandwidth and latency characteristics. Calculating the best route through such a complex system is computationally intractable and impossible to do by hand (D. Davies, D. Barber, W. Price and C. Solomonides 1979, J. Malrand 1991, W. Newton 2001).

If part of network becomes over_ filled with packets it can become impossible for packets to move. The queues into which they should be accepted are always full. This is called congestion. Routing algorithms strongly interact with congestion (D. Davies, D. Barber, W. Price and C. Solomonides 1979, G. Caro and M. Dorigo 1997).

2. Routing Using Fuzzy Logic

Routing algorithms in computer networks must be adapted to the traffic and topology changes. The information regarding these changes in network status is crucial for efficient routing of data. There is inherent uncertainty in this information because it is at least as old as the propagation delay between nodes. The changes in the status of the network are not immediately known to all the nodes in the network. The information available at the nodes at any time is often out_ of_ date as there is a delay between the occurrence of an event and the arrival of this information at all the nodes. This uncertainty is higher for information about nodes that are many hops away. Traditional network routing algorithms have not attempted to deal with this uncertainty in the information available at a node. Consequently, these algorithms often make poorer decisions when trying to route to distant nodes (S. Pithani and A. Sethi 1993).

Uncertain notions are described and implemented by fuzzy set theory. Therefore, in fuzzy logic an element can reside in more than one set to different degrees of similarity, and a formalism for implementing expert or heuristic rules is provided as fuzzy systems which are transparent. Then, the fuzzy systems can be integrated in complete routing systems (E. Aboelela 1998).

Considerable research has been devoted toward using fuzzy logic to solve the routing problem and to manage the congestion in the computer networks. M.Kara, H.Karablli and N.Duru (2003) propose an approach based on fuzzy logic for generating fuzzy cost of each path based on the crisp values of the different metrics possibly used in the network links. S. Rea and D. Pesch (2002) present a fuzzy logic based decision algorithm for ad hoc networks to instruct caching decisions and to optimize route selection. In the work of E. Aboelela and C. Douligeris (1998) the routing problem in the Broadband Integrated Services Digital Networks (B_ ISDNs) is formulated as a fuzzy multiobjective optimization model. The proposed model takes into consideration the balancing of the load in the network to avoid link saturation and hence the possibility of congestion.

3. Proposed Methods

This paper presents two proposed methods to use fuzzy logic for solving the routing problem in the computer networks. Fuzzy system is located at each node of the computer networks to make a local routing decision by using several criteria to evaluate the cost of sending a packet. In other method, the congestion control is combined with solving of the routing problem.

The computer networks which are considered in this paper modeled as graphs. Two examples, the first is a 9- node mesh computer network (CN1) shown in Figure (1). While the second is a random computer network (CN2) shown in Figure (2). The imposing values of cost of the links (packet delay) and queue length of the nodes for these two computer networks are shown in Tables (1) and (2), respectively. The values of the queue lengths in these Tables are located under changing continuously, when the nodes send or receive the packets.

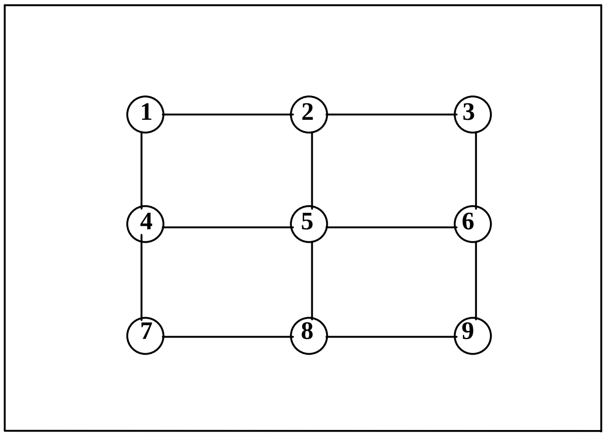

Figure (1) computer network (CN1)

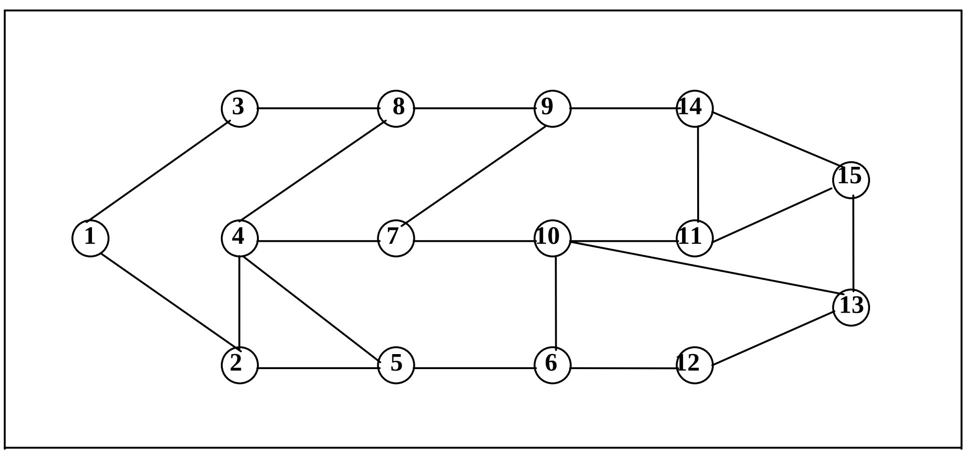

Figure (2) computer network (CN2)

Table (1) link costs and queue lengths of the computer network (CN1)

Links		Nodes	
link	cost (packet delay) (in second)	node	queue length (in packet)
1—2	10	1	6
1—4	2	2	5
2—3	3	3	8
2— 5	15	4	4
3— 6	8	5	7
4— 5	2	6	7
4—7	1.6	7	4
5— 6	1.2	8	6
5— 8	2.1	9	6
6— 9	1.5		
7— 8	3		
8— 9	1		

Table (2) link costs and queue lengths of the computer network (CN2)

Links		Nodes	
link	cost (packet delay) (in second)	node	queue length (in packet)
1—2	6.312	1	5
1—3	6.312	2	5
2—4	1.544	3	7
2— 5	6.312	4	7
3— 8	6.312	5	4
4— 5	3.352	6	8
4—7	6.312	7	8
4— 8	3.352	8	5
5— 6	12.624	9	6
6— 10	3.352	10	5
6— 12	6.312	11	4
7— 9	3.152	12	6
7— 10	3.152	13	3
8—9	6.312	14	4
9— 14	12.624	15	6
10— 11	3.152		
10— 13	3.152		
11— 14	3.152		
11— 15	3.152		
12— 13	6.312		
13— 15	6.312		
14— 15	6.312		

3.1. Routing Decision

A system is designed for solving the routing problem . It consists of central monitor and local routers. The router designed as fuzzy system (FL1), has three input variables, they are link_ time_ cost, queue_ time_ cost and neighbor_ destination_ path_ length, and two output variables, they are neighbor_ time_ cost and destination_ path_ level. Where link_ time_ cost is the packet delay on link to the one neighbor nodes, queue_ time_ cost is the waiting time of packet in queue of the one neighbor nodes, neighbor_ destination_ path_ length is the distance (number of the nodes) between the neighbor node of the router and the destination, neighbor_ time_ cost is the cost of sending packet by one neighbor node and destination_ path_ level is level of evaluating the suitability of the path from the router to the destination by the neighbor node. The linguistic values with trapezoidal or triangular membership functions of these variables are:

- (Low, Medium, High, Very high) of link_ time_ cost
- (Low, Medium, High, Very high) of queue_ time_ cost
- (Short, Medium, Long) of neighbor_ destination_ path_ length
- (Low, Medium, High, Very high) of neighbor_ time_ cost
- (Best, Good, Medium, Bad) of destination_ path_ level.

Table (3) shows the rule base of fuzzy inference for this system.

Table (3) the rule base of the fuzzy system (FL1)

Link_ time_ cost	Neighbor_ destination_ path_ length	Queue_ time_ cost: Low	Medium	High	Very High	Output variable
Low	Short	Low	Low	Medium	High	Neighbor_ time_ cost
		Best	Best	Good	Medium	Destination_ path_ level
	Medium	Low	Low	Medium	High	Neighbor_ time_ cost
		Best	Good	Good	Medium	Destination_ path_ level
	Long	Low	Low	Medium	High	Neighbor_ time_ cost
		Good	Good	Medium	Bad	Destination_ path_ level
Medium	Short	Low	Medium	Medium	High	Neighbor_ time_ cost
		Best	Good	Good	Medium	Destination_ path_ level
	Medium	Low	Medium	Medium	High	Neighbor_ time_ cost
		Good	Good	Medium	Bad	Destination_ path_ level
	Long	Low	Medium	Medium	High	Neighbor_ time_ cost
		Good	Medium	Medium	Bad	Destination_ path_ level
High	Short	Medium	Medium	High	Very high	Neighbor_ time_ cost
		Good	Good	Medium	Bad	Destination_ path_ level
	Medium	Medium	Medium	High	Very high	Neighbor_ time_ cost
		Good	Medium	Medium	Bad	Destination_ path_ level
	Long	Medium	Medium	High	Very high	Neighbor_ time_ cost
		Medium	Medium	Bad	Bad	Destination_ path_ level
Very high	Short	High	High	Very high	Very high	Neighbor_ time_ cost
		Medium	Medium	Bad	Bad	Destination_ path_ level
	Medium	High	High	Very high	Very high	Neighbor_ time_ cost
		Medium	Bad	Bad	Bad	Destination_ path_ level
	Long	High	High	Very high	Very high	Neighbor_ time_ cost
		Bad	Bad	Bad	Bad	Destination_ path_ level

The computer network contains the monitor at a central node and the fuzzy system (FL1) at each node. Exchange information is happened continuously between every node and its neighbor nodes. Then, every node has time cost to send packet on link and time cost of waiting the packet in queue to every neighbor node. For that, to send a packet to a destination node, the local fuzzy system receives time cost of link and time cost of queue of the one neighbor nodes, and also receives length of the path (number of the nodes) from this neighbor node to the destination node from the monitor. The fuzzy system gives as an output the time cost of this neighbor node for sending packet by it and level of evaluating the suitability of the path that contains this neighbor node for the arrival to the destination node. The local router (j) determines the best neighbor node in r_j steps. Where r_j is a number that represent the number of the neighbor nodes of the node j . For example, in the computer network (CN2), if node 8 has packet to send to node 14. Then, the fuzzy system in node 8 receives time cost of link, time cost of queue and path length to destination 14 of the one neighbor nodes (3, 4, 9), and determines the time cost of this neighbor node and level of evaluating the suitability of the path to destination 14 by this neighbor node. Therefore, after executing the fuzzy system for number of times as number of the neighbor nodes of node 8, the local router 8 determines its best neighbor node to reach destination 14 quickly. The same process is repeated at each node successively till the destination node.

3.2. Routing and Congestion Control

For solving the routing problem with congestion control, the system is designed as combination of two fuzzy systems. The first, fuzzy system (FL2) has two input variables, they are packet_ average_ level and packet_ variance_ level, and one output variable which is congestion_ prediction_ level. Where packet_ average_ level is level of estimating the average number of packets of a node, packet_ variance_ level is level of estimating the variance of packets of a node and congestion_ prediction_ level is level of determining the degree of congestion of a node.The linguistic values with trapezoidal or triangular membership functions of these variables are:

- (Low, Medium, High, Very high) of packet_ average_ level
- (Small, Medium, Big, Very big) of packet_ variance_ level
- (Zero, Short, Medium, Long) of congestion_ prediction_ level.

Table (4) shows the rule base of fuzzy inference for this system.

Table (4) the rule base of the fuzzy system (FL2)

Packet_ variance_ Level / Packet_ average_ Level	Small	Medium	Big	Very big	Output variable
Low	Zero	Zero	Short	Medium	Congestion_ prediction_ level
Medium	Zero	Short	Short	Medium	Congestion_ prediction_ level
High	Short	Short	Medium	Long	Congestion_ prediction_ level
Very high	Medium	Medium	Long	Long	Congestion_ prediction_ level

The second, fuzzy system (FL3) has two input variables, they are link_ time_ cost and congestion_ prediction_ level (the output of the first part (FL2)), and one output variable is the neighbor_ selection_ level. Where neighbor_ selection_ level is level of evaluating the suitability of the selected neighbor node. The linguistic values with trapezoidal or triangular membership functions of these variables are:

- (Low, Medium, High, Very high) of link_ time_ cost
- (Zero, Short, Medium, Long) of congestion_ prediction_ level.
- (Best, Good, Medium, Bad) of neighbor_ selection_ level.

Table (5) shows the rule base of fuzzy inference for this system.

Table (5) the rule base of the fuzzy system (FL3)

Congestion_ prediction_ Level / Link_ time_ cost	Zero	Short	Medium	Long	Output variable
Low	Best	Best	Good	Medium	Neighbor_ selection_ level
Medium	Best	Good	Good	Medium	Neighbor_ selection_ level
High	Good	Good	Medium	Bad	Neighbor_ selection_ level
Very high	Medium	Medium	Bad	Bad	Neighbor_ selection_ level

This routing system is included at each node of the computer network. Through exchange of information, each node obtains costs of links and statistics (average number of packets and variance of packets) of the neighbor nodes. The congestion predictor system (FL2) determines the congestion status of the neighbor nodes of node (j), in r_j _ steps. Where r_j is a number that represents the number of the neighbor nodes of the node j. At each step, the congestion predictor gives its output to the other fuzzy system (FL3) to determine selection level of neighbor node. For that, the routing system can make local decision to determine the best neighbor node, on that r_j _ steps. For example, in the computer network (CN1), if node 2 has packet to send to node 9, the congestion predictor (FL2) at node 2 gives the congestion state of the one neighbor nodes (1, 3, 5) to the fuzzy system (FL3) which decides selection level of this neighbor node. So, the selection level of each neighbor node can be determined. Then, the routing system at node 2 selects best neighbor node, that has less value of congestion prediction with less cost of link . The same process is repeated at each node successively till the destination node.

3.3. Simulation Result

The simulation has been realized using C++ programming language, for evaluating the efficiency of the proposed methods of using fuzzy systems to solve the routing problem. Through that, they are applied for two computer networks (CN1, CN2).

The proposed fuzzy systems have number of input linguistic variables, number of output linguistic variables and number of rules according to number of the linguistic values of the input variables as described in Table (6). The linguistic values of the input variables and the output variables with trapezoidal or triangular membership functions are shown in Figures (3)_ (5). In these Figures, the ranges of the membership functions are selected to cover the two computer networks (CN1, CN2). The rule base of these fuzzy systems is of Mamdani type. The Center of Gravity (CoG) method is used at defuzzification stage of these systems. The crisp value of the output variable is the value of the center of gravity of the membership functions given in equation (1).

$$\text{crisp value} = \sum_{i=1}^{n} c_i A_i \Big/ \sum_{i=1}^{n} A_i \qquad (1)$$

where n is the number of activition rules, c_i is the center of membership function, A_i is the area of activition part of membership function.

Some of the results of these fuzzy systems for the computer networks (CN1, CN2) are listed in Tables (7)_ (11). In these Tables, the values of the inputs and outputs variables corresponding to the linguistic values of the membership functions of these variables are given in Figures (3)_ (5).

From the simulation results, the following points are noticed.

- The structure of each proposed fuzzy system is not related to the size of the computer network.
- The inputs and the outputs of each proposed fuzzy system are information about the one neighbor nodes in the computer network.

Table (6) the number of input linguistic variables, output linguistic variables and number of rules of the proposed fuzzy systems

Fuzzy system	Number of input linguistic variables	Number of output linguistic variables	Number of rules
FL1	3	2	48
FL2	2	1	16
FL3	2	1	16

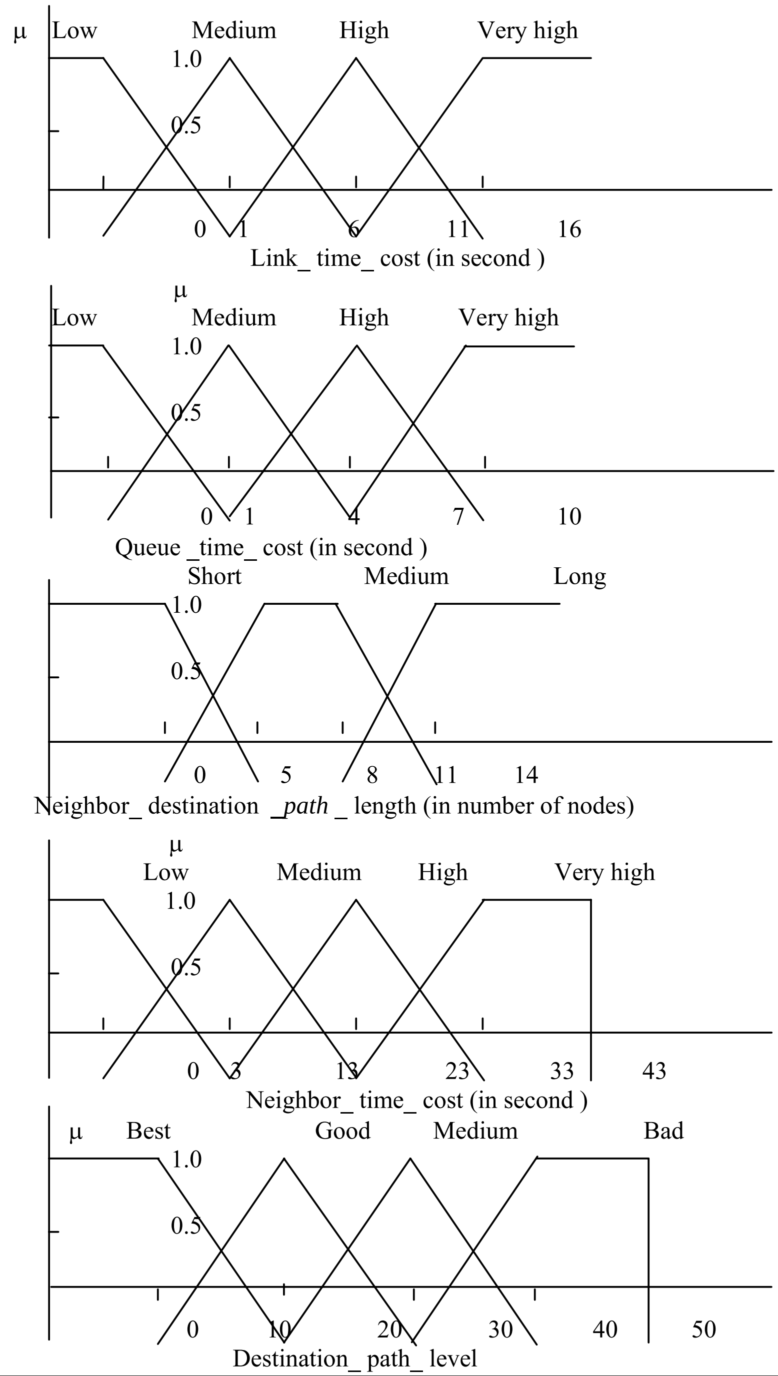

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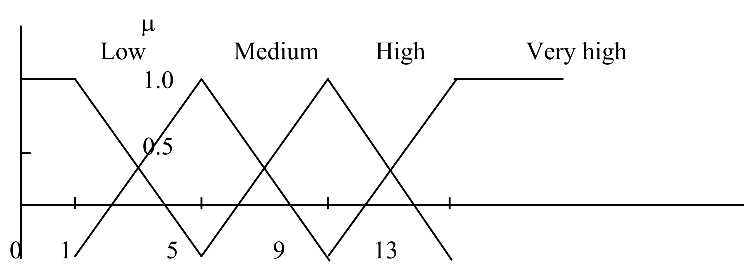
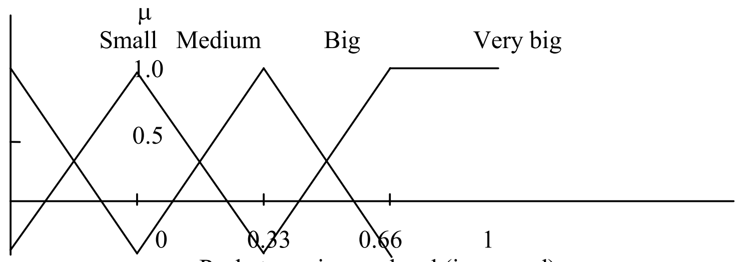
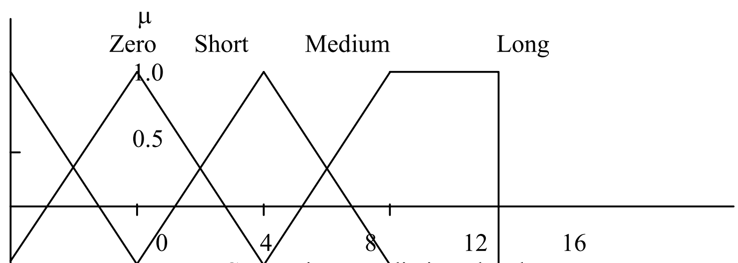
Figure (3) membership functions of the fuzzy system (FL1)



Packet_ average_ level (in packet)

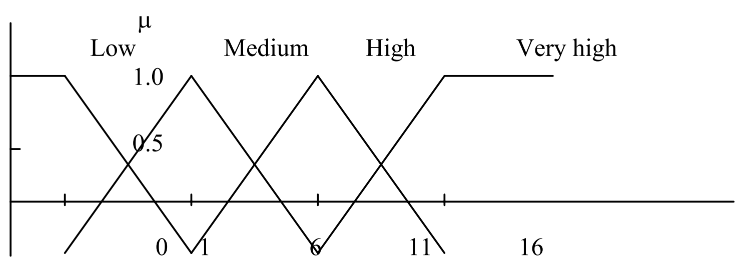


Packet_ variance_ level (in second)

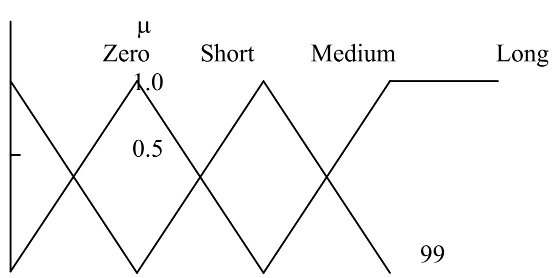


Congestion_ prediction_ level

Figure (4) membership functions of the fuzzy system (FL2)



Link_ time_ cost (in second)



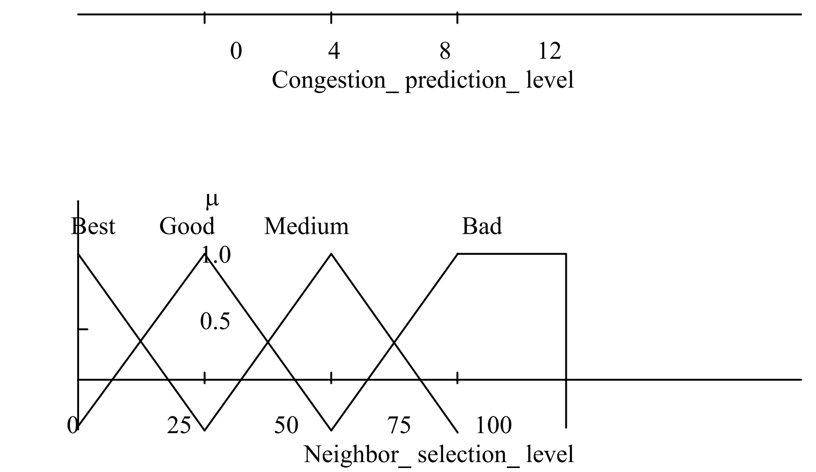


Figure (5) membership functions of the fuzzy system (FL3)

Table (7) some of the results of the fuzzy system (FL1) for the computer network (CN1)

Input variables			Output variables	
Link_ time_ cost (in second)	Queue_ time_ cost (Tq=Lq / P, let P=2) (in second)	Neighbor_ destination_ path_ length (in no. nodes)	Neighbor _ time_ cost (in second)	Destination_ path_ level
10	2.5	4	11.8825	18.3784
15	3.5	3	19.5535	26.5535
2	2	1	5.3485	11.6632
8	4	2	13	20
8	4	6	13	22.1441
10	2.5	8	11.8825	23.3784

Table (8) some of the results of the fuzzy system (FL1) for the computer network (CN2)

Input variables			Output variables	
Link_ time_ cost (in second)	Queue_ time_ cost (Tq=Lq / P, let P=2) (in second)	Neighbor_ destination_ path_ length (in no. nodes)	Neighbor _ time_ cost (in second)	Destination_ path_ level
3.352	2.5	3	6.3277	12.4482
12.624	4	5	16.7822	23.7822
6.312	3.5	2	11.594	17.9892
1.544	2.5	4	4.5653	11.0764
12.624	4	8	16.7822	33.7822
3.352	2.5	6	6.3545	14.6233

Table (9) some of the results of the fuzzy system (FL2) for the computer networks (CN1, CN2)

Input variables		Output variable
Packet_ average_ level /(in packet)	Packet_ variance_ level (in second)	Congestion_ prediction_ level
4	0.1	1.46316
9	0.4	5.13696
12	0.6	9.19229
13	0.8	12
1	0.1	0
6	0.5	4.73698

Table (10) some of the results of the fuzzy system (FL3) for the computer network (CN1)

Input variables		Output variable
Link_ time_ cost (in second)	Congestion_ prediction_ level (output of FL2)	Neighbor_ selection _ level
2	1.46316	7.0755
2.1	5.13696	18.3602
2	9.19229	35.1393
15	12	75
1.6	0	0
8	4.73698	28.8917

Table (11) some of the results of the fuzzy system (FL3) for the computer network (CN2)

Input variables		Output variable
Link_ time_ cost (in second)	Congestion_ prediction_ level (output of FL2)	Neighbor _selection _ level
3.352	1.46316	9.0804
6.312	5.13696	26.8333
12.624	9.19229	65.8843
12.624	12	75
12.624	0	25
3.352	4.73698	19.5252

4. Conclusions

The proposed methods which used fuzzy systems to solve the routing problem of the computer networks are described in this paper. These fuzzy systems can be included as a part of a routing system that contains a monitor for providing them with necessary information. The congestion control with solving of routing problem is realized at one of these proposed methods as a combination of two fuzzy systems. For making the routing decision, system contains central monitor and the fuzzy system (FL1) at each node, to determine the best neighbor node depending on two primary criteria that are link time cost and queue time cost. The fuzzy systems (FL2, FL3) as congestion predictor and routing decision maker are inculded at each node to manage routing with congestion control. Results of the fuzzy systems proof on their good performance for both computer networks (CN1, CN2).

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