# Reinforcement of A New Fuzzy Mixed Metric Approach Through Fuzzy Routing Algorithms

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**Summary**
Optimizing routing decisions has been an important subject in research of communication networks. Therefore, a new fuzzy mixed metric approach is introduced and the present paper proposes algorithms for the new fuzzy mixed metric approach, propounded to achieve improved routing decisions. The fuzzy approach proposes a mixed metric combining delay and load. The fundamental aim of the approach is to analyze the effect of the variability of load on delay. In other words, the approach is providing a fuzzy measure to quantify the effect of load on delay. The algorithms are proposed to provide a logical view of approach. Also, a routing model is proposed to understand the proposed approach more clearly and concisely.

***Key words:***
*Fuzzy routing algorithm, routing model, mixed metrics, fuzzy logic, distributed networks.*

## 1. Introduction

For achieving improved routing decisions a lot of efforts has been made by routing community. To achieve such an improved routing decision a fuzzy mixed metric approach is proposed. The approach is reinforced by using fuzzy logic theory to meet the prerequisites for optimized routing decisions. Fuzzy logic theory was instigated by Zadeh (1965) [9] and used to handle problems particularly in the fields of pattern recognition and communication of information.

Tan and Sacks [4] had also proposed a fuzzy mixed metric approach combining link utilization and delay metrics as input linguistic variables and using outputs as pure fuzzy figure for achieving improved routing decisions but the new one is found more cogent in terms of following aspects:-

- Using both dynamic entities (delay and load) to realize more sophisticatedly the variability factor of load.
- Accepting the values as such instead of normalizing them in any form.
- Defuzzification of variables is not performed in order not lose information.
- A complete new algorithm is devised to achieve routing decisions instead of using the existing ones.
- Satisfying QoS parameters for delay more cogently.
- Removes the imprecision of global state of the distributed networks as mentioned in [13].

The new fuzzy approach entails the three following major steps to obtain optimized routing decisions:-

- Formulation of fuzzy mixed metric
- Achieving a new link state packet format using the fuzzy mixed metric
- Consequently a new format of routing table is emerged, to achieve optimized routing decision.

The aim of the present paper is to propose the routing algorithms in parallel to the approach to achieve those optimized routing decisions. The algorithms are self explaining how the routing decisions are achieved for the proposed approach and a routing model is also proposed to explain the whole approach lucidly.

The paper is organized as follows. Section 2 discusses the proposed fuzzy approach in brief. Section 3 reinforces the algorithm with an explanation and proposes a simple routing model to understand the approach explicitly. Section 4 concludes the paper and outlines the future work.

## 2. The New Fuzzy Approach

The proposed approach introduces a fuzzy mixed metric formed from delay and load. Load's variability prompts us to realize it as a part of mixed metric. Therefore, allows to realize its effect on delay. The formation of mixed metric demands the construction of fuzzy sets and membership function corresponding to input and output linguistic variables and a rule matrix which will define a rule base upon which the decision will be based.

For input linguistic variables three fuzzy sets, Low, Average and High are defined and for output linguistic

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variables five fuzzy sets are defined i.e. Minimum, Low, Average, High and Maximum. Fuzzy sets are defined as a set consisting of vague boundaries [9]. On the other hand, a parallel membership function is a function, which yields a degree of strength to each value belongs to a fuzzy set. The grade of membership is given between [0, 1]. However, a rule base originates from a rule matrix formed of the two linguistic variables. Here, as both the inputs have three linguistic terms correspondingly. So, a 3 by 3 rule matrix is prepared and represented by figure1.

After defining fuzzy rules and membership functions, fuzzy inferencing is performed to reach the conclusion. After obtaining the prerequisite degree of strengths for each node, these values are stuffed into a new format of link-state packet as shown in fig.2.

New format for link state packets will consequently give rise to a more precise and coherent routing table. E.g.Figure3. shows such a sample of routing table.

The actual approach entails the comparison of degree of strengths for the Minimum output linguistic variable if and only if at least one entry for Minimum linguistic variable is non-zero. Otherwise, the next output linguistic variable is considered for decision making and so on. The logic behind the procedure is that "as suggested by literature that both delay and load are considered best with Minimum values, so output
mixed metric is also considered best with Minimum values. The more closer the degree of
strength to 1 for Minimum linguistic variable,

L O A D

| D E L A Y | Low | Average | High |
|---|---|---|---|
| Low | FR1 | FR2 | FR3 |
| Average | FR4 | FR5 | FR6 |
| High | FR7 | FR7 | FR9 |

**Figure.1The Fuzzy Rule Matrix**

| N1 | | | | | |
|---|---|---|---|---|---|
| Seq. | | | | | |
| Age | | | | | |
| Neigh. | Mixed Metric | | | | |
| | Min. | Low | Avg. | High | Max. |
| N2 | 0.24 | 0.48 | 0.24 | 0.0 | 0.0 |
| N5 | 0.37 | 0.74 | 0.37 | 0.0 | 0.0 |
| N3 | 0.0 | 0.25 | 0.50 | 0.25 | 0.0 |

**Figure2.New Structure Proposed for link-state packet**

| | N1 | N2 | N3 | N4 | N5 |
|---|---|---|---|---|---|
| **N1** | ∞ | 0.24 | 0.0 | ∞ | 0.26 |
| **N2** | 0.25 | ∞ | ∞ | 0.0 | 0.25 |
| **N3** | 0.0 | ∞ | ∞ | 0.0 | 0.12 |
| **N4** | ∞ | 0.25 | 0.25 | ∞ | 0.13 |
| **N5** | 0.37 | 0.50 | 0.12 | ∞ | ∞ |

**Figure3. A Sample Routing Table containing degree of strengths corresponding to 'low' linguistic term**

the better it is considered over others." For example,

| MM | Min. | Low | Avg. | High | Max. |
|---|---|---|---|---|---|
| C1 | *dsm1 | dsl1 | dsa1 | dsh1 | dsM1 |
| C2 | dsm2 | dsl2 | dsa2 | dsh2 | dsM2 |
| C3 | dsm3 | dsl3 | dsa3 | dsh3 | dsM3 |

*dsm – degree of strength for minimum linguistic term

If for Min. dsm1, dsm2 or dsm3 are non-zero entries.
Then Compare the three and bring out the degree closer to 1 Else Move on to the next output linguistic variable and repeat the procedure defined above until a set of non-zero entries are formed.

The next step is to reveal the best path or preference order of paths or a set of alternate paths for load balancing or transmission of packets. Therefore, the whole procedure could be implemented with the help of two algorithms 1) algorithm to compute the fuzzy mixed metric and 2) formulation to compute the best path or finding the preference order and alternate paths, using the concept of TE for load balancing.

Next section discusses both algorithms in detail and a routing model.

### 3. The Algorithms and Routing Model

*3.1 Algorithm to compute the output linguistic variable and assembling the routing table*

(a).Computation of Fuzzy Mixed Metric

Let MF is a system denoting the membership function and X is any value from the universal set of linguistic variables

Step-1 Put X into the MF system.
Step-2 Check the area in which X is lying i.e.
i) *If* perfectly lying in **Low** area
*Then* compute the degree of strength and assign to linguistic term low
ii) *If* in the area **Low & Average**
*Then* compute the degree of strength and assign the same to both fuzzy set.
iii) *If* exactly in **Average** area
*Then* assign the computed degree of strength to the fuzzy set **Average** only.
iv) *If* in area **Average & High**
*Then* compute the degree of strength and assign the same to both fuzzy sets.
v) *If* exactly in **High** area
*Then* compute and assign the degree of strength to fuzzy set **High** only.
Step-3 Install these degree of strengths with in the rule base.
Step-4 Compute the score of each rule using AND/MIN operation.
Step-5 Apply SUM composition to achieve the final degree of strength for linguistic terms defined for the output linguistic variable.
Step-6 Stop.

The algorithm is computing the degree of strengths for the crisp values of input linguistic variables. These degree of strengths are computed from a graphical triangular membership function. The crisp value lying in a particular area i.e. low, average, high, low-average or high-average, the same linguistic term will be assigned to its corresponding degree of strength. These degree of strengths are then input into the rule base having format like

If ***Low*** And ***Low*** Then ***Very low***

to achieve the degree of strength corresponding to each linguistic term. But, more than one non-zero consequents can be achieved through rule base for each linguistic term. So, to achieve the actual degree of strength corresponding to each linguistic term, SUM composition is used.

(b).The Logic of Assembling the Routing Table

Step-1 For any node N in the network perform the following:-
Search the Min linguistic term for non-zero entries.
If all entries are equal to zero
Then search the next term for non-zero entries.
Else put the corresponding entries in the routing table.
Step-2 Repeat step-1 until a set of non-zero entries are found
Step-3 Stop.

The above algorithm is representing the logic of assembling a routing table. The vital question arises is "How to fill the entries in the routing table". So, the above procedure is adopted and found well-suited to fill the entries in the routing table. The logic precedes is: to achieve the objective function of minimum delay and minimum load, that is, represented by mixed metric. Therefore, the minimum linguistic term for the output linguistic variable will serve prior to the other linguistic terms. So, the objective will be to move the grades corresponding to minimum linguistic variable first. And consider the others if and only if all the entries corresponding to minimum are zero.

The algorithms defined above are easily applicable. Thus, the fuzzy approach makes it simple and easy to use.

### *3.2. Proposed Routing Algorithm*

(a).Computation of Best Path

RT[S, D] is a 2D, N X N matrix representing a routing table. Where S, may be any source node 1 to N and D may be destination node 1 to N. DEST is a variable containing the final destination node. TEMP and NODE are one dimensional array to store the non-zero entries of routing table and the corresponding node position. NS is a one dimensional array to store the previously traversed nodes. I, J, K are the temporary variables

Step-1 For any source node S from 1 to N, select the best neighbour.
Step-2 Initialization, I=0, J=0, K=0
Step-3 NS[K] = S
K = K+1
Step-4 Repeat step-5 for D= 1, N
Step-5 If RT[S, D] ≠ ∞
Then J = J +1
TEMP[J] = RT[S, D]
NODE[J] = D
Step-6 Repeat step-7 for I = 1, J
Step-7 If TEMP[I] < TEMP[I + 1]
{
X = TEMP[I]

TEMP[I] = TEMP[I + 1]
TEMP[I + 1] = X
Y = NODE[I]
NODE[I] = NODE [ I + 1]
NODE[I + 1] = Y
}

*Sorts the list to give the preference order of nodes and their corresponding degree of strengths

Step-8 I = 1
Step-9 For K = 0 , K-1, repeat step-10
Step-10 If NODE[I] = NS[K]
{
I = I + 1
go to step-9
}
Step-11 If NODE[I] = DEST
Then STOP
Else S = NODE[I]
Step-12 Repeat steps 1 to 11 until destination is found i.e. DEST

The algorithm is computing the best path to route the traffic using the above steps, First, it selects a source S and save the initial source node in a one-dimensional array to store the previously traversed nodes. So that, they could not be encountered again and again to avoid loops. Now, in the routing table, each entry is checked for infinity (∞). If not, then the value and the corresponding nodes are stored in 1-d arrays and the values are compared to find the preferred node and their corresponding degree of strength. This node will be the best neighbour and now it is checked for whether it has been traversed earlier or not. If not traversed then it is checked for destination node. If the node is same as the destination node then stop the search else the whole procedure will be repeated till the destination is found.

(b). Computation of Preference order

Step-1 For any source node S from 1 to N, select the best neighbour.
Step-2 Initialization, I=0, J=0, K=0
Step-3 Repeat step-4 for D= 1, N
Step-4 If RT[S, D] ≠ ∞
Then J = J +1
TEMP[J] = RT[S, D]
NODE[J] = D
Step-5 Repeat step-7 for I = 1, J
Step-6 If TEMP[I] < TEMP[I + 1]
{
X = TEMP[I]
TEMP[I] = TEMP[I + 1]
TEMP[I + 1] = X
Y = NODE[I]
NODE[I] = NODE [ I + 1]
NODE[I + 1] = Y
}
Step-7 The preference order will be, repeat step-8 For I = 1, J
Step-8 Print NODE[I] elements
Step-9 STOP.

Where, X, Y are temporary variables.

This algorithm is giving us privilege to have a preference order in paths so that the high priority traffic could be transferred to the highly preferred node and low priority traffic on the second preferred node and so on. Therefore, the above algorithm is prioritizing the routes.

(c). Computation of set of alternate paths

Step-1 For any source node S from 1 to N,
Step-2 Initialization, I=0, J=0
Step-3 Repeat step-4 for D= 1, N
Step-4 If RT[S, D] ≠ ∞
Then J = J +1
TEMP[J] = RT[S, D]
NODE[J] = D
Step-5 Repeat step-6 for I =1, J
Step-6 If TEMP[I] = TEMP[ I + 1]
Step-7 Distribute load on each link represented by NODE[I] equally.
Step-8 STOP.

This algorithm founds a set of alternate paths i.e. the paths having equal priority to transfer traffic. In such cases, load balancing could be done to utilize all the paths simultaneously.

### *3.3 Routing Model*

A routing model parallel to the proposed strategy is represented in figure.4.

RB – Rule Base
MF – Membership Function
IN – Inference Engine

In relation to the routing model proposed in [05], a more simplified and thrifty routing model is proposed for the present approach. The present routing model broadly consists of three components. The very first component represents a set of crisp values corresponding to the routing metrics in consideration. These values are fuzzified using the MF and RB bits of the fuzzy system, the second component of the model. After fuzzyfying these inputs, the fuzzy inputs are sent to fuzzy inference system to compute the fuzzy costs of the path. Normally, these fuzzy costs are transferred into crisp costs using a defuzzification step. But, the present approach is making use of pure fuzzy figures to achieve improved routing decisions by using the routing algorithm proposed. The proposed routing algorithm allows to work for the three situations using the same algorithm as shown in fig.4. Using pure fuzzy costs, one could not only find the cheapest path normally as before but also achieve a preference order for the available paths to route the priority data. The concept of load balancing could be in use, on times these fuzzy costs provide a set of alternate paths.

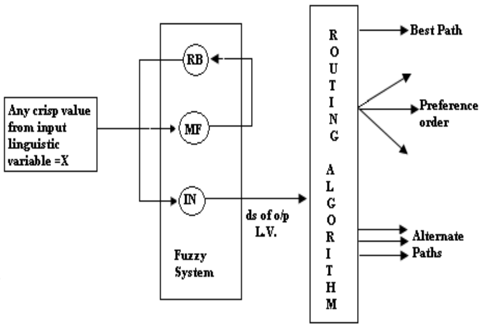


Figure.4 Routing Model

## 4. Conclusion and Future work

The present paper discusses the fuzzy routing algorithms in detail to achieve improved routing decisions. Each algorithm is cogent and easy to understand . Present algorithm consists of simple linear search and sorting methods, so are easily understandable. Also, a routing model is proposed to represent the whole procedure and easy to apprehend.

Future work is carried out in the light to analyze the performance and the proof of correctness of the approach.

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