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Abstract- Optimizing routing decisions has been an important subject in research of communication networks. The present paper is introducing a new fuzzy mixed metric approach, which takes routing decisions based on fuzzy costs in parallel to crisp cost of other metrics. The present paper evaluates the new fuzzy approach for its performance. The paper first describes the new fuzzy approach and the fuzzy routing algorithms developed for the approach and then the performance is evaluated both in empirical and analytical terms to show its advantages over the previous fuzzy approaches and traditional link-state routing approach. The paper analyzes the performance for different cases to show the efficacy of load on delay. The present paper bargains with three such cases.

Therefore, to achieve the above objectives the performance evaluation is done using a sample distributed network, to analyze it comprehensively.

Keywords: Fuzzy logic, mixed metric, packet-switched networks, fuzzy routing algorithms, performance evaluation.

1. Introduction

With the passage of time, various routing algorithms were introduced to achieve improved routing decisions. However, achieving optimized routing decisions is still a vital field of research in communication networks. A variety of routing techniques were introduced starting from shortest path routing to link-state routing to achieve better routing decisions over one another [04]. However, all the techniques were trade on the crisp values of metrics. Tan and Sacks [05] in 2001 introduced a fuzzy mixed metric approach, to achieve improved routing decisions over crisp values of delay metric. Tan and Sacks [05] approach got reinforcement from fuzzy theory, interposed by Zadeh (1965) [10]. Fuzzy set theory, completely non-statistical in nature was introduced to eradicate the sharp boundaries which divide the members of the class from non-members. Simplicity of fuzzy theory has prompted many researchers to use it in their work, like Aboelela and Douligeris [6, 7] has used it for developing a fuzzy inference system for Qos B-ISDN and introducing fuzzy link cost for routing in multimetric networks. Cohen, Korach and others [03] are generating a fuzzy based path ordering algorithms for imperfect Qos information. Chemouil, Khalfet and Lebourges [13] are introducing a fuzzy control approach for adaptive routing and Chanas [16] is making use of fuzzy sets of solving classical operational research problems. All these works are justifying the usefulness of fuzzy set theory in the field of communication networks.

In the present paper a new fuzzy approach is discussed and in parallel to the approach performance evaluation is done. The main objective of the paper will be to evaluate its performance both empirically and analytically. A sample packet switched network will remain as the basis to evaluate the performance of the approach. The results will be analyzed through line graphs for better understanding. The approach is tested for diverse conditions or cases, to analyze the results thoroughly.

The present paper is organized as follows. Section 2 views the new fuzzy approach and the corresponding routing algorithms. Section 3 provides an overview of the fuzzy routing algorithms. Section 4 deals with the objective of the paper i.e. the performance evaluation of the approach. Section 5 concludes the paper and outlines the future work.

2. Overview of 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 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 [10]. 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 figure 1.

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 of sample network as shown in fig.4 in section 4, 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. Figure 3 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, the better it is considered over others.

The next step is to reveal the best path or preference order of paths or a set of alternate paths for load balancing for 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. The next section discusses both algorithms.

3. The Fuzzy Routing Algorithms

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 to both fuzzy sets.

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.

(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

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
neighbor.
Step-2 Initialization, I=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

Computation of preference order within the paths and
finding the alternate paths will follow the same logic.

4. Performance Evaluation

The present paper evaluates the performance of the
new fuzzy routing algorithm with the help of an
example network. Therefore, the performance has been
realized, here, by considering a simple five node
distributed packet switched network (N,E), Where N is
the set of nodes i.e. N = {N1, N2, N3, N4, N5} and E is
the set of links i.e. E = {l1, e2, …e8}.

Consider N1 be the source and N4 as destination. N2,
N5 and N3 are the neighbors to N1. The delays on the
three links from node N1 to its neighbors are computed
traditionally (using round-trip time) and the load would
be considered at an instant of time t on that particular
node. However, the upper bounds for delay and load
with in a network are computed using the following
equations:-

\[ \text{High} = \frac{\text{max Load}}{\text{link capacity}} \]  \hspace{1cm} \text{(1)}

\[ \text{High} = \text{maximum buffering capacity of} \]
\[ \text{the router} \]  \hspace{1cm} \text{(2)}

For illustration, let the link capacity of each link e is
5pac/sec, and the maximum buffering capacity at each
node is 40packet. Therefore, the upper bound for delay
is computed as follows:-
Max. Delay $D = \frac{40}{5} = 8$ s

Using equation (1) and the upper bound for load will be the maximum buffering capacity.

Let the delay values for node $N1$ are

$N1-N2 = d1 = 3$ s  
$N1-N5 = d2 = 2.5$ s  
$N1-N3 = d3 = 7$ s

(*Delay here is computed traditionally)

For node $N2$

$N2-N1 = 3$ s  
$N2-N5 = 2$ s  
$N2-N4 = 4$ s

For node $N3$

$N3-N1 = 7$ s  
$N3-N5 = 3.5$ s  
$N3-N4 = 4.5$ s

For node $N4$

$N4-N2 = 4$ s  
$N4-N5 = 5$ s  
$N4-N3 = 4.5$ s

For node $N5$

$N5-N1 = 2.5$ s  
$N5-N2 = 2$ s  
$N5-N3 = 3.5$ s  
$N5-N4 = 5$ s

and load at time $t$, $N1 = 35$ packets, the load queued for the neighbors of $N1$ as follows:-

$N2 \rightarrow 15$ packets  
$N5 \rightarrow 8$ packets  
$N3 \rightarrow 12$ packets

Similarly, for $N2 = 25$ packets, load queried for its neighboring nodes are:-

$N1 \rightarrow 8$ packets  
$N5 \rightarrow 7$ packets  
$N4 \rightarrow 5$ packets

For $N3 = 30$ packets, load queried for its neighbouring nodes are:-

$N1 \rightarrow 10$ packets  
$N5 \rightarrow 5$ packets  
$N4 \rightarrow 15$ packets

For $N4 = 15$ packets, load queried for its neighbouring nodes are:-

$N2 \rightarrow 5$ packets  
$N5 \rightarrow 6$ packets  
$N3 \rightarrow 4$ packets

For $N5 = 20$ packets, load queried for its neighbouring nodes are:-

$N1 \rightarrow 6$ packets  
$N2 \rightarrow 3$ packets  
$N3 \rightarrow 6$ packets

Therefore, from membership functions for both delay and load, the degree of strengths are computed as follows:-

The corresponding membership functions for delay and load are:-

*Figure 5*

These degrees of strengths are computed on the basis of its crisp value lying in a particular region and therefore, for each node, combinations are formed of delays (on their neighboring nodes) and the load queried for that particular node. Therefore, a set of combinations has been formed for each node and the corresponding degree of strength for each combination is given below:-

For node $N1$

$O_{pmm1} = C1 = dsd1 + dsl1$  
$O_{pmm2} = C2 = dsd2 + dsl2$  
$O_{pmm3} = C3 = dsd3 + dsl3$

For node $N2$

$O_{pmm1} = C1 = dsd1 + dsl1$  
$O_{pmm2} = C2 = dsd2 + dsl2$  
$O_{pmm3} = C3 = dsd3 + dsl3$

For node $N3$

$O_{pmm1} = C1 = dsd1 + dsl1$  
$O_{pmm2} = C2 = dsd2 + dsl2$  
$O_{pmm3} = C3 = dsd3 + dsl3$

For node $N4$

$O_{pmm1} = C1 = dsd1 + dsl1$  
$O_{pmm2} = C2 = dsd2 + dsl2$  
$O_{pmm3} = C3 = dsd3 + dsl3$

For node $N5$

$O_{pmm1} = C1 = dsd1 + dsl1$  
$O_{pmm2} = C2 = dsd2 + dsl2$  
$O_{pmm3} = C3 = dsd3 + dsl3$

For node $N1$, $N2$, $N3$, $N4$ and $N5$ the degree of strength of the output linguistic variables are:-

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Low</th>
<th>Avg</th>
<th>High</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C1$</td>
<td>0.24</td>
<td>0.48</td>
<td>0.24</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$C2$</td>
<td>0.37</td>
<td>0.74</td>
<td>0.37</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>$C3$</td>
<td>0.0</td>
<td>0.22</td>
<td>0.50</td>
<td>0.25</td>
<td>0.0</td>
</tr>
</tbody>
</table>
The degree of strengths corresponding to linguistic terms of the output linguistic variable are puffed into the link-state packet to give rise to a new format of link-state packets as shown in fig. 2. New format of link state packets will consequently give rise to a more precise and coherent routing table as shown in fig 3. Hence, yielding more accurate and improved routing decisions.

Accuracy of the routing decisions can be checked from figure 6. Analyzing fig. 6(a) it can be seen that in 6(a.1) the Min line graph entails the highest degree of strength for node N5. In parallel to 6(a.1), 6(a.2) is showing the routing decision based on both the metrics i.e. fuzzy mixed metric and delay metric. The accuracy of the decision could be measured from the point that both the approaches are pointing to the same node as the next best node to route the traffic. Figure 6(b), 6(c), 6(d) are advocating the result drawn by 6(a). However, 6(e) is showing N1 as the best node according to fuzzy mixed metric instead of N2.

In 6(e), according to fuzzy mixed metric N1 would be the next best node to route the traffic. However, its counter part delay metric suggest N2 as the next best node customary. This is happening so, in this case, as the load is playing the vital role here, instead of delay. This case would be discussed later in this section. The preciseness of fuzzy cost can be analyzed over the crisp delay values with the help of the following figure in taking the optimized routing decisions.

The performance is illustrated here, in terms of efficacy of load on delay in achieving improved routing
decisions. Therefore, three such cases are taken in consideration below.

**Case-I. Analyzing the effect of High and Low Load conditions on delay**

It has been analyzed, empirically that two types of routing decisions are taken under two parallel load conditions i.e. load [low-avg] and load[avg-high].

Generally, the routing decisions under these two load conditions would be taken as:

**Case-I.1** If load [low-avg] then the *RD[MM] will be the same as **RD[DM].

*RD[MM] - Routing decision based on Mixed Metric

**RD[DM] - Routing decision based on Delay Metric

A sub case of case-I.1 will be, when all the load values are in range [low-avg], then of all the load values, the value tending more closer to Min plus the delay value not closer to Min. would be considered as the best combination to route. The case analyzes the effect of load on delay with the help of following diagram:-

Figure 8 suggests N5 as the next routing node, however, the delay at this node is more as compared to node N2, therefore, according to delay metric, N2 should be considered as the next best routing node.

**Case-I.2** If load [avg-high] then the RD[MM] will not be the same as RD[DM].

But, as the load assigned at N5 is approximately half of the load assigned to node N2. Therefore, the effect of load on delay can be seen transparently. The difference in taking routing decision in the later case and the present case, therefore can be analyzed from the above graphs.

**Effect of Low Load Conditions**

\[ \rho(L) \alpha(\text{load, delay}) \quad \ldots (i) \]

\[ \sigma(\text{load, delay}) \alpha \text{MM}(l,d) \alpha \text{RD}(MM) \quad \ldots (ii) \]

As discussed above, in sub case of case-I.1, the basis of routing decision has changed in contrast to the traditional method of achieving routing decisions. Here, \( \rho(L) \) in equation (i) is representing the load values tending towards ‘Minimum’ fuzzy set, \( \sigma \) (load, delay) is representing the efficacy of load on delay. Equ.(i) is representing a directly proportional relationship between the two. As under various circumstances, the minimum or low load values are directly affecting the delay values. It is known that efficacy of load on delay could be measured with the help of fuzzy mixed metric. Therefore, the routing decisions taken on the basis of fuzzy mixed metric will be affected directly. This gives rise to the proportional relation between the three parameters \( \sigma \) (load, delay) i.e. effectiveness of load on delay, \( \text{MM}(l,d) \) fuzzy mixed metric formed from load and delay and \( \text{RD}(MM) \) is the routing decision based on the mixed metric as shown in equ. (ii).

**Effect of High Load Conditions**

\[ \delta(L) \alpha(\text{load, delay}) \quad \ldots (i) \]
σ (load, delay) α MM(l,d) α RD(MM) ...(ii)

As discussed above, in sub case of case-I.2, the nodes with high load conditions in combination with lower delay values would not be considered as the best possible node to route the traffic, therefore, again directly affecting the way routing decision were taken as shown in fig.9. δ (L) is representing the load values tending towards high load fuzzy set.

Case-II Analyzes the case where a set of alternate paths is supported by the approach. For this, the following case values are considered.

Let at node N1 the delay values to its neighboring nodes are:

(d1'') N1-N2 = 1s  
(d2'') N1-N5 = 3s  
(d3'') N1-N3 = 5s

And the total load at N1 is 20, which is distributed to its neighboring nodes in the following way:-  

(e1'') Æ N2 = 5 packets  
(e2'') Æ N5 = 15 packets  
(e3'') Æ N3 = 5 packets

Therefore, the new set of combinations in the form of degree of strengths is formed for node N1 as follows:-

For node N1

Opmm1'' = C1 = dsd1'' + dsl1''  
Opmm2'' = C2 = dsd2'' + dsl2''  
Opmm3'' = C3 = dsd3'' + dsl3''

Hence, for C1 the degree of strength (ds) for output fuzzy sets is:-

\[
\begin{array}{cccccc}
\text{Min} & \text{Low} & \text{Avg} & \text{High} & \text{Max} \\
C1: & 0.0 & 0.25 & 0.50 & 0.25 & 0.0 \\
\end{array}
\]

Similarly, for C2 and C3 the corresponding degrees of strengths are:-

C2: 0.0 0.25 0.50 0.25 0.0
C3: 0.0 0.25 0.50 0.0 0.0

Now, from the above computations it can be seen that C1, C2 and C3, all can be considered equally best, to route the traffic. In such cases, the concept of traffic engineering (TE) can be used to exploit the full advantage of the fuzzy approach i.e. to route the traffic on all the three paths at the same time. However, the traditional approach only allows to route traffic on one best path. The concept can be made more clear by analyzing it through graphs given below:-

The above graph is showing clearly that if routing decision is taken based on crisp delay, there will be only one best node to route the traffic while at the same time if the fuzzy mixed metric is considered for taking the routing decision, will provide all the three nodes as the best node to route the traffic in spite of the different delay values, therefore, showing the effect of load on delay. This allows to implement the concept of traffic engineering which allows to route the traffic on all the three route simultaneously.

Case-III Setting of routes according to priority of traffic, here, is considered as the third most important case as satisfying the Qos parameter **.

Consider the line graph of node N2, clearly gives the first best node, second best node and third best node in case we have priority assigned data. Therefore, the high priority data could be shifted to node 5 then a lower priority on node N1 and the least priority data on node N4. Hence, a preference order for priority assigned traffic would be revealed.

Hence, the approach provides an efficient way to evaluate the effect of load on delay under assorted situations. It also establishes a unique pattern to analyze the fuzzy figures. Therefore, the approach defined here, quite so analyzes the effect of variability of load.

These are some of the empirical results on the performance of new fuzzy mixed metric approach. Analytically, the following points are revealed in favor of the new approach. The algorithms described in section 3 eradicated the problem existing in previously proposed techniques. Such as, it eliminates the impression of the global state of the distributed networks mentioned in [QOSR], by allowing filling real
numbers ranging 0-1 i.e. degree of strengths for the corresponding fuzzy metric instead of approximate numeric values. The algorithm also handles the Qos factors for delay in a more meticulous manner by providing path constrained path optimization routing.

5. Conclusion and Future Work

The present paper is evaluating the new fuzzy mixed metric approach in different aspects to analyze its performance over the traditional approach. The paper is presenting many new aspects for taking routing decisions. It has been analyzed that the preciseness of fuzzy metric is more than the delay metric in taking routing decisions. Also there are a variety of ways to interpret the routing decisions in spite of just getting one best node to route the traffic. A preference order can be designed for priority traffic as described in case-III. Also, there can be a scenario in which we could exploit all the routes at the same time besides there are different values of delay and load. The most important fact that is realized is the effect of load on delay, as the approach is selecting the best node whose delay is high as compared to its neighboring nodes only because the corresponding load is lower on that node as compared to its neighboring nodes. Therefore, various results are drawn with one approach.

Future works reveals the correctness of the approach by simulating it.

References


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