# REALIZATION OF A NEW FUZZY MIXED METRIC APPROACH FOR OPTIMIZING ROUTING DECISIONS IN PACKET SWITCHED NETWORKS

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**ABSTRACT**

The paper illustrates a new fuzzy approach for optimizing routing decisions. This illustration is being done, here, using packet switched networks. It implements the approach and analyzes the new coherent formats of link-state packets and routing table accrued from the implementation of approach. In this algorithm, each node in the network maintains a database containing values corresponding to linguistic variables described for the output mixed metric formed from delay and load. Therefore, describing the complete network topology more meticulously. Because the traffic in the network is quite variable, therefore, it is combined with delay to yield more efficacy in achieving improved routing decisions. Also, provides a fuzzy measure to quantify the effect of load on delay.

Thus, the whole procedure is implemented over an example of packet switched network to analyze its working comprehensively.

Keywords: Fuzzy logic, mixed metric, distributed networks, fuzzy algorithm, routing decisions.

## 1. INTRODUCTION

The problem of optimizing routing decisions has been one of the most intensively studied areas in the field of communication networks. Optimization of routing decisions means optimizing routing metrics, as metrics are foundation for routing decisions. Therefore, a lot of efforts has been done by the routing community in this direction. Fuzzy set theory instigated by Zadeh [9] has also been in role to optimize these metrics. Fuzzy set theory, completely non-statistical in nature is used to handle problems particularly in the fields of pattern recognition and communication of information [9]. Therefore, application of fuzzy logic in routing in communication networks has been implemented in [15], [12], [6], [4], [5].

Also, the theory is used to deal with imperfect Qos information in [3].

The objective of present paper is to formulate and implement new fuzzy approach and analyze the accrued prerequisite coherent new link state packet and routing table formats.

The paper is organized as follows. Section 2 defines the scope of delay and load as fuzzy metrics. Section 3 formulates the new fuzzy mixed metric approach. Section 4 realizes the new approach using an illustrative example. Section 5 concludes the paper and outlines the future work.

## 2. SCOPE OF DELAY AND LOAD

The new fuzzy approach is based on a mixed metric. For the formation of fuzzy mixed metric, the two input variables (delay and load), here, are employed as linguistic variables instead of arithmetic variables. Linguistic variables are those whose values are words or sentences in natural artificial language than numbers [05]. Hence, a linguistic approach is deployed to formulate the scope of input variables. The use of this customary language allows to modify the range specified for variables, both input and output. Therefore, providing the advantage of scaling, to achieve more preciseness for the linguistic variables defined.

The scope of input variables (delay and load), for the approach, is outlined as:-

Here, delay as linguistic variable defined with linguistic terms low, average and high. The orbit of these words is defined as:-
Low = 0, as minimum delay of a packet could be zero

Average = here it is taken as half of the maximum value for simplicity i.e. High/2

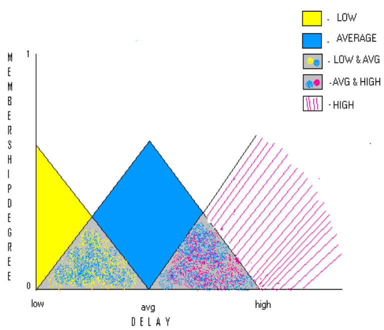


**Fig.1 Membership Function for Delay**

High = (max_Load)/(link_capacity) (1)

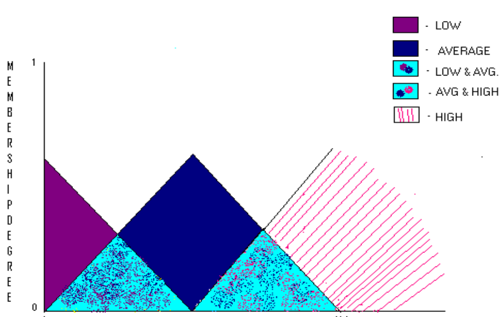


**Fig. 2 Membership function for load**

Similar linguistic terms are defined for load, however, it is not necessary to do so :-

Low = 0, as the minimum load on any router could be zero

Average = like delay, it is taken as half of the max value i.e. high/2

High = maximum buffering capacity of the router (2)

Figures 1 and 2 highlights the areas indicating where the low, average or high values or a combination of these will fall.

## 3. FORMULATION OF NEW FUZZY APPROACH

After defining the scope of input variables (delay and load), their corresponding degree of strengths are computed using their corresponding membership functions. These grades are then used as input in the rule base to achieve the degree of strengths corresponding to output linguistic terms. A rule base is a statement consisting of If And Then Else e.g.

If *Low* and *Low* Then *Very Low*

Where the condition part corresponds to input linguistic terms and the consequent part corresponds to output linguistic term. Using different rules a rule matrix is formed, which provides more than one degree of strength for each output linguistic term. Then SUM composition is used to achieve the final responses for output linguistic terms of fuzzy mixed metric.

Now, on the basis of fuzzy mixed metric, a new structure for link-state packets is proposed and consequently, a series of link state packets for each node will give rise to a new format of routing table.

## 4. REALIZATION OF THE APPROACH

The present paper focuses on the comprehensive functionality of the approach discussed in section 3 and yields a new framework for routing. Before the illustration of the approach, some assumptions are specified. That are, 1) Buffering capacity of each router will be same 2) delay in one direction and its reverse direction will be same 3) all the links throughout the network bears equal link capacities. Here, the approach is realized 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 = {*l*1, *l* 2,. ., *l* 8}.

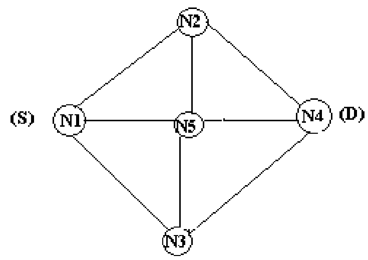


Fig. 3 Illustrative Network

Consider N1 be as 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 equations (1) and (2).

For illustration, let the link capacity of each link l 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 = 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 → 15 packets
N5 → 8 packets
N3 → 12 packets

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

N1 → 8 packets
N5 → 7 packets
N4 → 5 packets

For N3 = 30 packets, load queued for its neighboring nodes are:-

N1 → 10 packets
N5 → 5 packets
N4 → 15 packets

For N4 = 15 packets, load queued for its neighboring nodes are:-

N2 → 5 packets
N5 → 6 packets
N3 → 4 packets

For N5 = 20 packets, load queued for its neighboring nodes are:-

N1 → 6 packets
N2 → 3 packets
N3 → 6 packets
N4 → 5 packets

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

*Computation of strengths for input delay and load values*

The corresponding membership functions for delay and load are:-

Therefore, the computed degree of strengths (ds) for input delay (d1, d2, d3) values and load values are:-

For node N1

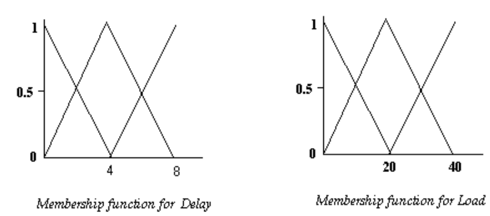


**Fig.4**

ds for d1 = 0.24 = low = average, high=0.0
l1 = 0.25 = low = average, high=0.0
ds for d2 = 0.37 = low = average, high=0.0
l2 = 0.39 = low = average, high=0.0
ds for d3 = 0.25 = average = high, low=0.0
l3 = 0.45 = low = average, high=0.0

For node N2
ds for d1 = 0.25 = low = average, high=0.0
l1 = 0.39 = low = average, high=0.0
ds for d2 = 0.50 = low = average, high=0.0
l2 = 0.35 = low = average, high=0.0
ds for d3 = 1 = average, low = high = 0.0
l3 = 0.26 = low = average, high=0.0

For node N3
ds for d1 = 0.25 = average = high, low=0.0
l1 = 0.50 = low = average, high=0.0
ds for d2 = 0.12 = low = average, high=0.0
l2 = 0.26 = low = average, high=0.0
ds for d3 = 0.13 = average = high, low=0.0
l3 = 0.25 = low = average, high=0.0

For node N4
ds for d1 = 1= average, low = high = 0.0
l1 = 0.26 = low = average, high=0.0
ds for d2 = 0.13 = average = high, low =0.0
l2 = 0.30 = low = average, high=0.0
ds for d3 = 0.25 = average = high, low =0.0
l3 = 0.20 = low = average, high=0.0

For node N5
ds for d1 = 0.37 = low = average, high=0.0
l1 = 0.30 = low = average, high=0.0
ds for d2 = 0.50 = low = average, high=0.0
l2 = 0.15 = low = average, high=0.0
ds for d3 = 0.12 = low = average, high=0.0
l3= 0.30 = low = average, high=0.0
ds for d4 = 0.25 = average = high, low=0.0
l4 = 0.26 = low = average, high=0.0

These degree of strengths are computed on the basis of its crisp value lying in a particular region (refer fig, (1) or (2)) and therefore, for each node, combinations are formed of delays (on their neighboring nodes) and the load queued for that particular node. Therefore, a set of combinations in the form of degree of strengths is formed for each node as follows:-

For node N1
Opmm1 = C1 = dsd1 + dsl1
Opmm2 = C2 = dsd2 + dsl2
Opmm3 = C3 = dsd3 + dsl3
For node N2
Opmm1 = C1 = dsd1 + dsl1
Opmm2 = C2 = dsd2 + dsl2
Opmm3 = C3 = dsd3 + dsl3
For node N3
Opmm1 = C1 = dsd1 + dsl1
Opmm2 = C2 = dsd2 + dsl2
Opmm3 = C3 = dsd3 + dsl3
For node N4
Opmm1 = C1 = dsd1 + dsl1
Opmm2 = C2 = dsd2 + dsl2
Opmm3 = C3 = dsd3 + dsl3
For node N5
Opmm1 = C1 = dsd1 + dsl1
Opmm2 = C2 = dsd2 + dsl2
Opmm3 = C3 = dsd3 + dsl3
Opmm4 = C3 = dsd4 + dsl4

Here, only the computations are done for node N1 and for rest of the nodes the membership grade of their output linguistic terms will be specified, as the basis of computation will remain the same.

For node N1

For Opmm1 = C1 = dsd1 + dsl1
Delay
dsd1 = 0.24 = low = average, high = 0.0
Load
dsl1 = 0.25 = average = high, low = 0.0

Put these computed degree of strengths from membership functions into the rule base

Therefore,
Rule1: If D is low and L is low Then
Output ( 0.24 & 0.25) = 0.24
Rule2: If D is low and L is avg Then
Output ( 0.24 & 0.25) = 0.24
Rule3: If D is low and L is high Then
Output ( 0.24 & 0.0) = 0.0
Rule4: If D is avg and L is low Then
Output ( 0.24 & 0.25) = 0.24
Rule5: If D is avg and L is avg Then
Output ( 0.24 & 0.25) = 0.24
Rule6: If D is avg and L is high Then
Output ( 0.24 & 0.0) = 0.0
Rule7: If D is high and L is low Then
Output ( 0.0 & 0.25) = 0.0
Rule8: If D is high and L is avg Then
Output ( 0.0 & 0.25) = 0.0
Rule9: If D is high and L is high Then
Output ( 0.0 & 0.25) = 0.0

Using AND rule, the minimum of the two values is extracted. It is also observed that only rules (1, 2, 4, 5) are producing non-zero results. Therefore, a SUM composition is performed to know the exact degree of strength for each output fuzzy set, as :-

Min = R1 = 0.24
Low = R2 + R4 = 0.24 + 0.24 = 0.48
Avg = R3 + R5 + R7 = 0.0 +0.24+0.0 = 0.24
High = R6 + R8 = 0.0 + 0.0 = 0.0
Max = R9 = 0.0

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

| | Min | Low | Avg | High | Max |
|---|---|---|---|---|---|
| C1: | 0.24 | 0.48 | 0.24 | 0.0 | 0.0 |

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

| | | | | | |
|---|---|---|---|---|---|
| C2: | 0.37 | 0.74 | 0.37 | 0.0 | 0.0 |
| C3: | 0.0 | 0.25 | 0.50 | 0.25 | 0.0 |

The above enumerated values are themselves telling which is the best combination. As it is cleared C2 combination is lying most closer to 1, both in Min and Low fuzzy sets as compared to other combinations. But, on the other hand, if Avg. fuzzy set is analyzed it is seen that C3 combination is much closer to 1 as compared with the rest. This situation is giving rise to an argument “Which combination is best either C2 or C3”. The explanation to the argument is here, “as it is known that both delay and load will be at its best when they are minimum, so the algorithm will only goes from ‘Min’ fuzzy set to ‘Max’. As soon as it finds the non-zero degrees in any of the earlier fuzzy set it will compare the degrees for that set only keeping all other fuzzy sets ignored. As our example is explaining, firstly the fuzzy set Min is explored for its non-zero values i.e. 0.24, 0.37 and 0.0, which are indicating that the input values of C1 are Min up to 0.24 degree, C2 is Min up to 0.37 degree and the values corresponding to C3 are not altogether Min as the degree of strength is zero. But, in Avg. fuzzy set, its degree is 0.50, though closer to one but indicating that the corresponding input values are medium type. Therefore, will not be treated as the best path for routing information.

Similarly, for node N2, N3, N4 and N5 the degree of strength of the output linguistic variables are :-

For node N2

| | Min | Low | Avg | High | Max |
|---|---|---|---|---|---|
| C1: | 0.25 | 0.50 | 0.25 | 0.0 | 0.0 |
| C2: | 0.35 | 0.70 | 0.35 | 0.0 | 0.0 |
| C3: | 0.0 | 0.26 | 0.26 | 0.0 | 0.0 |

For node N3

| | Min | Low | Avg | High | Max |
|---|---|---|---|---|---|
| C1: | 0.0 | 0.25 | 0.50 | 0.25 | 0.0 |
| C2: | 0.12 | 0.24 | 0.12 | 0.0 | 0.0 |
| C3: | 0.0 | 0.13 | 0.26 | 0.13 | 0.0 |

or node N4

| | Min | Low | Avg | High | Max |
|---|---|---|---|---|---|
| C1: | 0.0 | 0.26 | 0.26 | 0.0 | 0.0 |
| C2: | 0.0 | 0.13 | 0.26 | 0.13 | 0.0 |
| C3: | 0.0 | 0.20 | 0.40 | 0.20 | 0.0 |

For node N5

| | Min | Low | Avg | High | Max |
|---|---|---|---|---|---|
| C1: | 0.30 | 0.60 | 0.30 | 0.0 | 0.0 |
| C2 : | 0.15 | 0.30 | 0.15 | 0.0 | 0.0 |
| C3: | 0.12 | 0.24 | 0.12 | 0.0 | 0.0 |
| C4: | 0.0 | 0.25 | 0.50 | 0.25 | 0.0 |

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. New formatted link-state packets of each node are shown in figure5. The information with in these packets could be analyzed with the help of graphs as shown in figure6. Each graph is defined in parallel with the packets defined in figure5.

The approach is providing a preference order with respect to paths. Analyzing figure.6(a) one can easily observe that N5 will be given preference first as N5 bears a degree closer to 1 in each required fuzzy sets i.e. Min and Low. It is also observed that N5 is bearing the same degree of strength for Avg. fuzzy set as in Min fuzzy set. Thus, it can be easily concluded that output metric value is a low type value, as the degree of strength for low is more closer to 1 as compared to the degree of strength of Min and Avg. fuzzy sets. With a graphical representation one can easily get through the preference order i.e. N5, N2, N3. A similar case exists for node N2, i.e. N5 is the best neighboring node having Low type value. Analyzing Fig.6(c) it is observed that only for N5 there is a single non-zero entry for Min linguistic term. Thus, determining it as the best node. However, according to Low term N1 is the best node as the degree is more closer to 1 than N5 but at the same time if high linguistic term is analyzed, N1 has a greater degree of strength for this fuzzy set establishing the fuzzy metric for N1 as a high value. However, N5 is least high as compared to both N1 and N4. Comparing the degree of strengths for N5 for all the linguistic terms in a row, it is concluded that it is a Low type value and thus chosen as the highest preferred node. Similarly, fig.6(d) declares N2 as the preferred node in contrast to its counter parts. However, its counter parts bear a greater degree of strength for the average linguistic term but at the same time N2 has more precise identity in the low fuzzy set as compared to its counter parts. Fig.6(e) categorically declares N1 as the next best node for transferring information packets having Low type value among all others.

New format of link state packets will consequently give rise to a more precise and coherent routing table. Hence, yielding more accurate and improved routing decisions. The routing table for the present scenario is as follows:-

**Source – N1**

| Destination | BN | Ds | AN | Ds | AN | Ds |
|---|---|---|---|---|---|---|
| N1 | - | - | - | - | - | - |
| N2 | N5 | 0.37 | N2 | 0.24 | | |
| N3 | N5 | 0.37 | N2 | 0.24 | N3 | 0.0 |
| N4 | N5 | 0.37 | | | | |
| N5 | N5 | 0.37 | | | | |

**BN - Best node to route traffic**
**AN-Alternate Node**
**Figure.7. Routing Table for present example containing degree of strengths corresponding to 'low' linguistic term for Node N1**

The above routing table for node N1 is showing all the best possible paths for each destination of N1. Therefore, the cost comparison of two paths would be done on the criteria – 'Each track of the path should contain degree of strength greater than its alternate best neighboring node'. For example, for destination as node N2, there are two best possible nodes to route the traffic, first is through Node N5 and the alternate is node N2, the node itself. But, the path starting with node N5 may or may not be the best path. It would be considered as the best path only if, all the intermediate tracks consists of the degree of strength greater than the degree of strength at node N2. Now, the question is 'How these entries to be filled up in the routing table'? Observation reveals that the aim is to give preference to the paths according to minimum delay and load values, that is, the preference order would be minimum, low, average, high and maximum value. Therefore, the degree of strengths corresponding to minimum linguistic term are analyzed first. If they contain non-zero entries, only then, they are to be filled into the routing table, otherwise, move on to the next linguistic term to check the elements of it. The procedure will be repeated until a set of non-zero entries are found. Therefore, explored up to the maximum linguistic term. This is the procedure to fill the routing table, 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 formation of routing table 2) to compute the best path or finding the preference order and alternate paths, using the concept of TE for load balancing.

However, the cultivation aspect of these algorithms will be the scope of future work.

## 5. CONCLUSION AND FUTURE WORK

The present paper comprehensively illustrates a new fuzzy mixed metric approach in packet switched networks. In parallel to this it proposes the new formats of link state packets and routing table. Previously, in link-state routing, routing table consists of delay metric values corresponding to the neighboring nodes. These values, however, were imprecise in nature, in the sense, that they were computed using round-trip time of the packet, which used to be an average value. The present approach, here, is computing the values using fuzzy approach making them more precise in nature and thus, supports to achieve improved routing decisions, and also facilitates the eradication of impreciseness lying in the global information.

Future work entails the cultivation and implementation of the routing algorithms for the approach defined in the present paper.

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| 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 |

(a)

| N2 | | | | | |
|---|---|---|---|---|---|
| Seq. | | | | | |
| Age | | | | | |
| Neigh. | Mixed Metric | | | | |
| | Min. | Low | Avg. | High | Max. |
| N1 | 0.25 | 0.50 | 0.25 | 0.0 | 0.0 |
| N5 | 0.35 | 0.70 | 0.35 | 0.0 | 0.0 |
| N4 | 0.0 | 0.26 | 0.26 | 0.0 | 0.0 |

(b)

| N3 | | | | | |
|---|---|---|---|---|---|
| Seq. | | | | | |
| Age | | | | | |
| Neigh. | Mixed Metric | | | | |
| | Min. | Low | Avg. | High | Max. |
| N1 | 0.0 | 0.25 | 0.50 | 0.25 | 0.0 |
| N5 | 012 | 0.24 | 0.12 | 0.0 | 0.0 |
| N4 | 0.0 | 0.13 | 0.26 | 0.13 | 0.0 |

(c)

| N4 | | | | | |
|---|---|---|---|---|---|
| Seq. | | | | | |
| Age | | | | | |
| Neigh. | Mixed Metric | | | | |
| | Min. | Low | Avg. | High | Max. |
| N2 | 0.0 | 0.26 | 0.26 | 0.0 | 0.0 |
| N5 | 0.0 | 0.13 | 0.26 | 0.13 | 0.0 |
| N3 | 0.0 | 0.20 | 0.40 | 0.20 | 0.0 |

(d)

| N5 | | | | | |
|---|---|---|---|---|---|
| Seq. | | | | | |
| Age | | | | | |
| Neigh. | Mixed Metric | | | | |
| | Min. | Low | Avg. | High | Max. |
| N1 | 0.30 | 0.60 | 0.30 | 0.0 | 0.0 |
| N2 | 0.15 | 0.30 | 0.15 | 0.0 | 0.0 |
| N3 | 0.12 | 0.24 | 0.12 | 0.0 | 0.0 |
| N4 | 0.0 | 0.25 | 0.50 | 0.25 | 0.0 |

(e)

**Figure.5** *New format of link-state packets for (a) node N1 (b) node N2 (c) node N3 (d) node N4 (e) node N5*

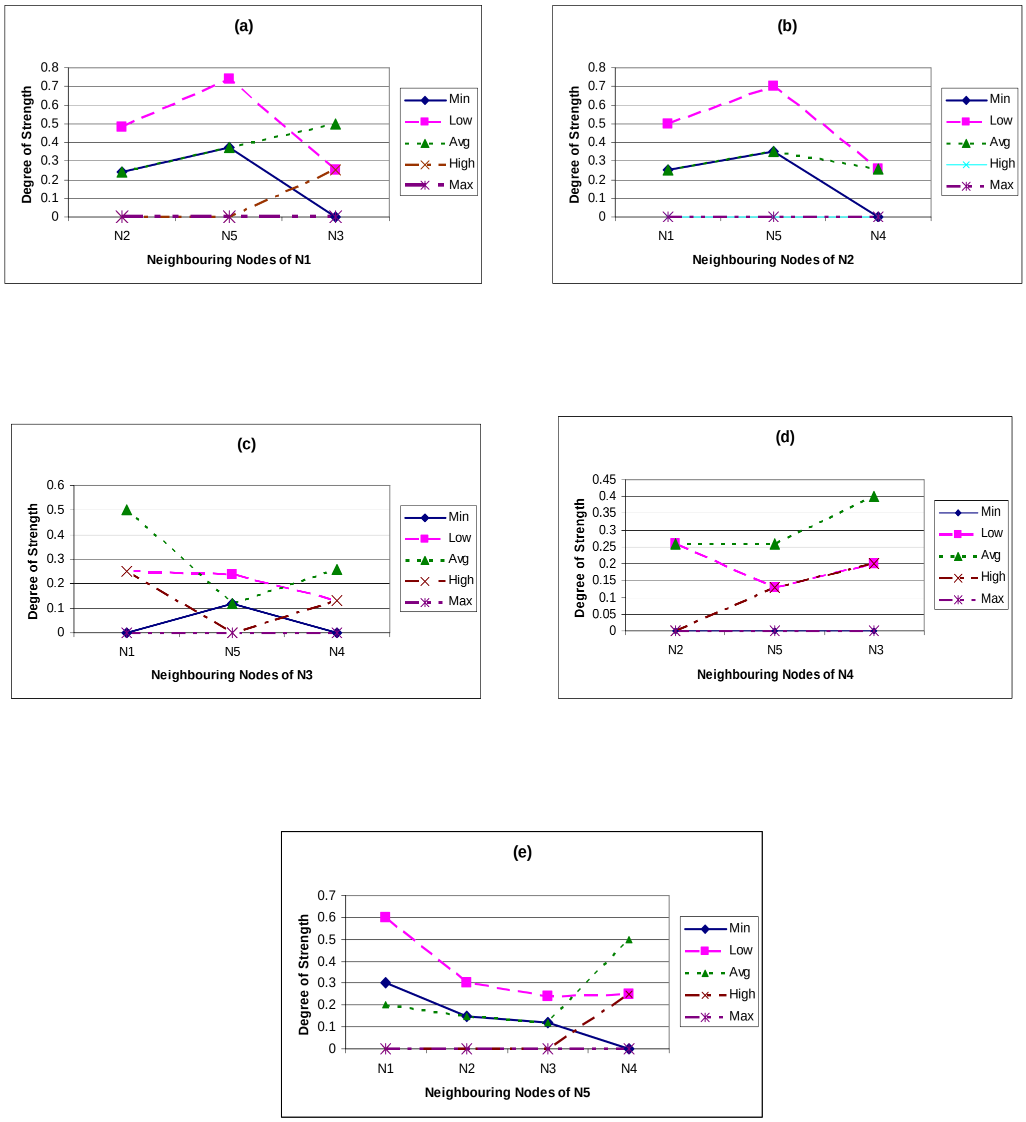


**Figure.6 a)** *Clearly, shows the best neighbouring node along the best path when source is N1. b), c), d) and e) also shows the best neighbouring nodes to proceed for a best path when the sources are N2,N3, N4, N5 for a destination.*