CHAPTER 6

CONCLUSION

6.1 INTRODUCTION

This chapter reviews the significance of the proposed routing algorithms, the results obtained during the present work and suggestions for future research. Before proceeding with the review of the work done, the objectives of the thesis started earlier in the introductory chapter are recalled.

The primary objective of this research is to develop hybrid optimal Internet routing algorithms that account for the optimality and the unpredictable behaviour of the links between source and destination. Based on this objective it is proposed to develop new approaches that are derived from specific soft computing paradigms such as fuzzy logic and neural networks for Internet routing analysis.

6.2 HIGHLIGHTS OF THE WORK DONE

The thesis offers fresh motivation for fundamental algorithms that are finding new applications in the context of Internet routing and emphasizes the fact that the models proposed depend on informed opinions with shortage of numerical evidence. A linguistic model is implemented to analyse Internet routing. The link performance is expressed using fuzzy variables and various routing models have been developed.

A brief survey of the routing algorithms available in the literature is discussed in the introductory chapter and the motivation for the present work is also brought out.
A fuzzy opinion matrix is constructed by considering the subjective estimation of the message transmission rate by many users while transferring the message through all possible links. A mathematical model has been developed to estimate the fuzzy hamming distance between the user opinion about the transmission rate of each link and the expected message transmission rate. The estimated fuzzy hamming distances are used as cost metric of links and based on that hybrid routing algorithms are implemented. To make the algorithms more effective and to obtain realistic results in optimal routing new concepts such as fuzzy Laplacian criteria, fuzzy Hurwicz criteria and fuzzy minimax regret principles are introduced. Sensitivity analysis has been carried out to verify the correctness of the algorithms. Based on the investigations made and results obtained, the following conclusions are arrived at:

i. The fuzzy exhaustive search algorithm identifies the correct optimal path all the time successfully when the network size is small. When network size increased the algorithm requires more computational time and memory space since this algorithm searches all the possible combinations of links to identify all the possible paths. This algorithm is able to suggest near optimal paths as alternative paths for routing during busy traffic time to avoid congestion.

ii. The fuzzy priority based algorithm identifies the correct optimal path most of the times with minimum number of searches and requires less computational time and memory space since this algorithm quickly identifies the next intermediate node considering only the directly connected links of the previously identified node, makes a level by level greedy search for the minimum fuzzy hamming distance link. Because the search is made only with the local information of the directly connected links not worrying about the previous or forthcoming information of the other nodes, the complexity is much less than the other algorithms but for the same reason the algorithm is not able to identify the correct optimal path all the time being trapped into local minima. The advantage in this
algorithm is that it is always able to identify the near optimal path quickly with less complexity.

iii. The fuzzy shortest path algorithm identifies the correct optimal paths all the time. Even though the complexity is higher, the advantage is that this algorithm is able to explore the correct optimal paths from a given source node to all the other nodes. The routing computation is an implementation of Dijkstra's routing algorithm.

iv. The fuzzy pruning algorithm identifies the correct optimal path all the time much faster than the other discussed algorithms, since the algorithm continues its search every time after verifying the optimality condition whenever a new path is identified selecting only the partial links whose cumulative fuzzy hamming distance is less than an upper bound value. This upper bound is set by the difference of minimum cumulative fuzzy hamming distance of the identified paths and the minimum fuzzy hamming distance among all the links. While verifying the optimality condition, the algorithm avoids searching all the partial paths, which cannot reduce the path cost, by pruning the partial paths whose cumulative hamming distances are greater than this upper bound. Also this algorithm is able to identify near optimal paths as alternative paths by changing the upper bound value of the last iteration with new upper bound considering the cumulative fuzzy hamming distance of the next minimal path, and the minimum fuzzy hamming distance among all the links. The complexity of this algorithm is in between the fuzzy priority routing and the fuzzy exhaustive search routing as lower and upper bounds respectively. Only in its worst case of search the algorithm’s complexity of search goes to the upper limit, which seldom results.

v. A multiobjective routing model is developed to explore the optimal path, which satisfies more than one objective such as fast sending path, more
reliable path from a given source to destination. The fuzzy hamming distance of every link is estimated from expected fuzzy set and the overall opinion of the users about the link expressed in terms of the multiobjective criteria. The expected fuzzy set is computed from the expected fuzzy sets of different objective by finding their minimum membership values. The overall opinion about every link is also computed as the intersection of users opinions about the link expressed in terms of different objective criteria considered. Using these fuzzy hamming distances as weight matrix, the proposed routing algorithms are applied to identify the optimal path, which satisfies the various objective criteria such as fast sending path, more reliable path.

vi. Dynamic routing is achieved by implementing a fuzzy heteroassociative neural network. In this model fuzzy opinions are generated periodically in a minimum duration of time. The fuzzy pruning algorithm identifies the optimal path and the near optimal paths from a given source to the requested destination. These paths are stored in a heteroassociative neural network along with specific time intervals. The trained neural network is able to recall the path and readily provides the best on-line path to the router for its requested destination.

vii. The concept of unfamiliar path is introduced to find an alternative path during traffic congestion.

viii. Sensitivity analysis is carried out to verify the correctness of the results obtained by the hybrid routing algorithms due to the change in users' opinions about various links and its effects on the optimal path.

Since the developed routing techniques depend on the informed opinions, which may vary from time to time based on the users' attributes, few enhancements are incorporated as follows to estimate the fuzzy hamming distances.
• A fuzzy Laplacian criterion is introduced by estimating the average of the fuzzy hamming distance between the opinions about each link and the expected message transmission rate.

• A fuzzy Hurwicz criterion is introduced to take into account the optimistic or pessimistic opinions of users with an optimism-pessimism index.

• A fuzzy minimax regret principle is introduced to take into account the amount of worth lost by not choosing a better decision for finding the optimal path.

In these enhancements, the arithmetic operations involved in estimating the fuzzy hamming distance of each link is considerably reduced. These enhancements were tried out in all the routing algorithms developed and realistic results were obtained in all cases. The comparisons of results were reported.

6.3 FURTHER RESEARCH

This research is not intended for a small circle of followers. The new routing techniques introduced in this research deal with informed opinions. The linguistic variables are quantified arbitrarily and the construction of the membership functions is a problem when eliciting opinions. There appears to be no agreed way of proceeding. The author suggests further research in constructing suitable membership functions when the performance of the links is expressed in terms of an expert’s subjective opinions.

An intelligent device at every router which could do automatic generation of fuzzy opinions based on the results obtained from suitable measuring tools such as TCP dump can be thought of in the On-Line Routing Model using fuzzy heteroassociative neural network.
Since the thesis concentrates on introducing new techniques for exploring optimal routing in an environment with unpredictable changes, the user's / expert's opinion about each link is arbitrarily generated and the sample size is kept to a minimum. The algorithms are to be tested in a real time environment with a data sample collected from large number of users. The algorithms developed in this research are applied and tested with a system of six nodes and 17 links, 20 nodes and 54 links and 40 nodes and 107 links and satisfactory results were obtained. The performance of these algorithms has to be tested in a real Internet traffic environment or with sub network of interest.

The inclusion of user's / expert's opinions into an analytical scheme makes optimal path search more realistic. The fuzzy based routing algorithms proposed in this thesis can be considered as better alternatives for making routing decisions under uncertainties while comparing with the existing probabilistic and heuristic techniques.