Fuzzy Logic Controlled Energy Efficient Routing in Mobile Ad-Hoc Networks

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Abstract— **In this work, we have proposed IAOMDV-F protocol which is a modified version of AOMDV protocol by embedding a fuzzy controller Best Route Selector (FBRS). The fuzzy controller FBRS selects the best path from the available multiple paths with objectives of optimized energy consumption and to provide more stable path. It applies fuzzy logic to three input parameters – average mobility, queue length and distance between consecutive nodes and then determines path selection index to find best path. The performance of the proposed protocol has been evaluated and compared with AODV, AOMDV and AOMDV-F protocols across different performance metrics – end to end delay, throughput, packet delivery rate and energy consumption. The results show that the proposed IAOMDV-F protocol outperforms other protocols. NS-2 environment was used to simulate and analyze the proposed protocol.**

***Index Terms** - Multipath; Fuzzy Logic; AOMDV; Mobility; Queue Length; Distance;*

I. INTRODUCTION

Mobile Ad Hoc Network (MANET) has established its credibility due to ease of deployment and wide spread applications. However, dynamic topology, communication channel characteristics and limited battery life of nodes makes the design of these networks difficult and present a number of challenges to research community. The energy constraint is the key challenge in the ad-hoc networks. Energy is consumes in to establish route, to route recovery and maintenance, and for communication process. To discover the route, the source has to initiate a path discovery phase to determine path(s) to destination. Further, path breakdown is a predominant phenomenon in MANET due to above mentioned factors and more specifically, can be attributed to node failure due to overload, high mobility or node speed, energy drained node, out of transmission range node, path attenuation, etc. These indirectly cause path discovery to become nearly a periodic task and in turn affect battery life as well as route stability adversely. The existing limitations of these networks have motivated research community to hunt for energy efficient routing protocols.

The existing protocols provide single or multiple paths from the source to destination. The problem with single path routing protocol is, if path breakdowns the whole route discovery process will have to be repeated to re-establish the path followed by re-transmission of lost packets, leading to unnecessary energy consumption and delay. Ad-hoc On Demand Distance Vector (AODV) routing protocol [1] is an example of single path provider protocol. On the other hand, advantages with multipath routing protocols is, if route fails, one of the alternate routes available to be used which give support to save battery power and avoid unnecessary delay. A number of multipath routing protocols are devised for mobile ad hoc networks [2], for example - Distance Source Routing (DSR) protocol [3], Ad-Hoc On-Demand Multiple Distance Vector Routing (AOMDV) protocol [4], fuzzy base protocol AOMDV-F [5] etc.

AOMDV-F [5] protocol is a modified version of AOMDV protocol and makes use of fuzzy method to select a path from the multiple paths list consists of all the possible paths between source and destination prepared during discovery phase by AOMDV. Then AOMDV-F[5] is used in selection process based of fuzzy control methodology. The fuzzy control process is based on two parameters – residual node energy and hop-count while path selection is based on maximum residual node energy and minimum hop-count. The selected path is shortest path and most un-utilized nodes combination path in the network. The protocol increase life-time and performance of network as compared to AOMDV but not concern about energy conservation and path stability. AOMDV-F has following limitations in path selection process: (i) Let path have fewer hop-counts but if average distance between nodes of path is large then path consume more battery power during transmission [6, 7] due to more distance; (ii) as node-load has not been considered in its path selection criteria it may cause congestion leading to increase in loss of packets resulting in unnecessary power consumption in lost packet retransmission [8]; (iii) further, protocol has not taken node-mobility into account, if the selected path has a node with adequate power but very high degree of mobility, probability of path failure will increase, resulting in more battery power consumption in path rediscovery phase or retransmission of lost packets. The average link duration of path (stability of path) decreases with increase in node speed

[9, 10], hence mobility is an important parameter for routing in an ad-hoc network.

The above shortcoming of AOMDV-F motivated us to design a routing protocol which is energy efficient and stable. In the proposed protocol, the path-list generation by AOMDV and selects the best path by using fuzzy technique similar to AOMDV-F but fuzzification process is quite different. To overcome the discussed limitation of AOMDV-F, the path selection process is improved in the proposed protocol that is to say as Improved Ad-hoc On Demand Multi-Path Distance Vector - Fuzzy (IAOMDV-F). IAOMDV-F is use to select path by fuzzy controller which is based on the input parameters - average queue length, average mobility and average distance between nodes of the path.

The queue length directly affects the battery life of a node and indirectly the network lifetime. It is established that longer the queue length at a node, greater the probability of congestion and packet loss at that node, results in increased energy consumption [11, 12]**.** The second input parameter selected is the mobility (node speed). The probability of a node moving out of transmission range increases with increase in mobility, giving higher link failure rate. This again increases energy consumption due to need of route reestablishment and lost packet retransmission [13]. The node mobility also have impact on path stability, higher the mobility, less will be the path stability [10]. The third selected input parameter, the distance between two consecutive nodes of the path is important because the distance directly affects the transmission power of a node and indirectly the energy consumption and attenuation. This is also leads to higher probability of route failure and packet loss that further augments the energy consumption [14]. The fuzzy controller optimizes these parameters and use by proposed protocol.

In this paper the main focus is on the design of a fuzzy controlled energy efficient and stable routing protocol IAOMDV-F. The rest of the paper is organized as follows: Section-II presents the design of proposed protocol and fuzzy controller. Simulation and performance analysis is given in section-III and finally section-IV offers our conclusions.

II. PROTOCOL DESIGN AND FUZZY LOGIC CONTROLLER

A. *Design IAOMDV-F Protocol*

The protocol IAOMDV-F is based on AOMDV protocol which is again a modified version of AODV. AOMDV protocol discovers multiple paths during discovery phase and buffers the path-list at the node. Each discovered path is assigned a unique sequence number. In the beginning best path is selected from the path-list and whenever the active path fails, it selects an alternate path from the list. The IAOMDV protocol significantly differs from AOMDV and AOMDV-F in path selection process from the path-list. The fuzzy model used our proposed protocol is also different from AOMDV-F. Figure-1 summarizes the algorithm of the designed protocol IOAMDV-F. The *Fuzzy Based Route Selector (FBRS)*, the fuzzy controller used for path selection in the proposed protocol is discussed subsequently.

B. *Fuzzy Route Selector*

The fuzzy controller called *Fuzzy Best Route Selector* (FBRS) is designed and developed to select the best path out of the path list provides by AOMDV as shown in Figure 2. The proposed FBRS takes average queue length, average distance and average speed as input and generates selection index of the given path as output. The major components of the route selector are fuzzifier, fuzzy rule base, inference engine and defuzzyfier. The fuzzifier based on the fuzzy logic fuzzifies the numerical values of the input parameters into fuzzy values – low, medium and high. The interface engine receives input from fuzzifier and map onto fuzzy rules to get fuzzy selection index. The proposed FBRS fuzzy controller has twenty seven fuzzy rules. The defuzzifier converts the fuzzy selection index into the selection index and presents as output.

Input Parameters:

Path list given by AOMDV protocol

Output:

Select the optimum path from path list

Protocol Processed Steps:

1. Start
2. Sending the request packet RREQ from the source node to the relevant neighbours;
3. Forward the packet to the relevant neighbours up direction;
4. If the receiver node is not destination node Then go to step 2;
5. AOMDV Finds multiple path and stored in linked list PathList from source to destination;
6. Call Algorithm ABRS (PathList) and return the best path from list;
7. The destination node sends the reply packet RREP through the selected path to the source to the destination;
8. Use the selected best path for data transmission.
9. End

Figure-1 Design of IAOMDV-F Protocol

In contrast to AOMDV-F [5] which takes residual energy and hop-count as input parameters in path selection process, the proposed protocol uses three input parameters – queue length, distance and mobility. The drawbacks in AOMDV-F are already discussed in section-I, the reasons behind the selection of proposed input parameters are discussed here. The aim of the proposed protocol is not only minimising the energy consumption but to provide a more stable path between the source and the destination.

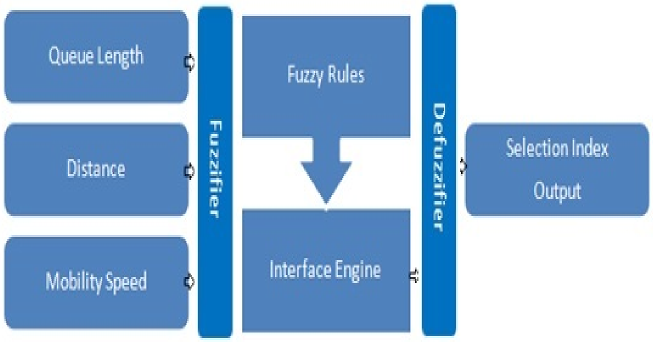

Figure-2 Fuzzy Best Route Selector (FBRS)

The queue length directly affects the battery life of a node and indirectly the network life. It is established that longer the queue length at a node, more is the probability of congestion and packet loss resulting more energy consumption [11-12]. The second input parameter selected is the mobility (node speed). The probability of a node moving out of transmission range increases with increase in mobility, giving higher link failure rate. This again increases energy consumption due to need of route reestablishment and lost packet retransmission [13]. The node mobility also have impact on path stability, higher the mobility, less will be the path stability [10]. The third selected input parameter, the distance between two consecutive nodes of the path is important because attenuation will increase rapidly with distance, hence should more transmission energy. This may lead to packet loss and greater probability of route failure which, further augment the energy consumption [14].

```
Algorithm FBRS ( pathlist)
{       for each path from pathlist do
        {       // analysing each path from source to destination
                Evaluate the average queue length of nodes in the path;
                Evaluate the average Speed of nodes in the path;
                Evaluate the average Distance with consecutive nodes in the path;
                Fuzzify input numeric values;                  //Fuzzification process
                Calculate fuzzy selection index using Fuzzy Rules; //Interface Engine
                Defuzzify selection index and store;           //Defuzzification
        }
        Select path with maximum selection index
        return path;
}
```

Figure-3 Algorithm of Fuzzy controller (FBRS)

The Fuzzy Best Route Selector (FBRS) algorithm designed for selection of best path is given in Figure 3. The best path is selected out of the path list determined by using AOMDV protocol and given as input to fuzzy controller FBRS. The fuzzification Process, rule-base and interface engine, defuzzification process and criteria for best path selection are described here.

a) ***Fuzzification process:*** This involves mapping of numeric values of various input parameters onto fuzzy values used in the fuzzification process of the controller. The fuzzy values used in this design are low, medium, and high. The fuzzifier finds the average values of input parameters - average queue length ***(£)***, average mobility ***(μ)*** and average distance ***(d)*** using formulas given by Eq. 1, Eq. 2 and Eq. 3 respectively.

$$£ = \frac{\sum \text{queue length at each node}}{\text{number of nodes in the path}} \quad (1)$$

$$\boldsymbol{\mu} = \frac{\sum \text{mobility speed of each node}}{\text{number of nodes in that path}} \quad (2)$$

$$\boldsymbol{d} = \frac{\sum \text{Distance } \textit{from source to destination}}{\text{number of nodes in that path}} \quad (3)$$

The fuzzifier makes use of Fuzzy membership function to map numerical values of £, *μ and d* onto fuzzy values – Low, Medum and High.

b) ***Interface engine and rule base:*** The interface engine receives the fuzzy values of average queue length, average mobility and average distance as input from fuzzifier and apply the fuzzy rules designed for determination of fuzzy selection index of each path. The selection index tells about the quality of path. In the proposed approach fuzzy value 'High' denotes best path and 'Low' represent the worst path based on our performance criteria.

c) ***Defuzzification:*** This section of fuzzy controller is responsible for conversion of Fuzzy selection index received from interface engine as input in numeric value. The selection index for each path is determined and stored with path.

d) ***Best path Selection Criteria*****:** The selection index is indicative of minimum energy consumption and high stability path. The path selection algorithm of the fuzzy controller finally determines the best path by using selection index of each path. The path having highest selection index is designated as the best path.

III. SIMULATION AND PERFORMANCE ANALYSIS

The simulation model in this study consists of a network area of 1000mx1000m in which nodes are free to move at defined speed. The mobility is modeled using Random Way Point Mobility Model [15]. The energy consumed/losses in transmission, receiving, and idle mode is modeled according to Bansal Energy Overhead Model [16]. It is assumed that all nodes initially have equal energy. The simulation parameters are summarized in Table-I.

TABLE -I: SIMULATION PARAMETERS

Number of nodes	1 to 100
Terrain range	1000m × 1000m
Transmission range	Up to 100 m
Average node degree	03-05
Node's mobility speed	0-15 m/s
Mobility model	Random way point
Propagation model	Free space
Channel bandwidth	4 Mbps
Links delay	20-200 ms
Traffic type	CBR
Data payload	512 bytes/packet
Node pause time	0-10 seconds
Protocols	AODV, AOMDV, AOMDV-F, FDRDP
Simulation Time	500 ms
Energy Model	Bansal Energy Overhead Model

Network Simulator (NS-2) [17] is used to simulate AODV, AOMDV, AOMDV-F, and IAOMDV-F protocols. The above mentioned parameters are used for simulation and comparison of different protocols with proposed IAOMDV-F protocol under different scenarios. The FBRS fuzzy controller of IAOMDV-F uses the fuzzy membership values for input parameters as given in Table-II.

TABLE -II FUZZY MEMBERSHIP OF INPUT PARAMETERS

Input Parameters → Fuzzy values ↓	Average Queue Length(£) (no's)	Average Mobility($\boldsymbol{\mu}$) (m/sec)	Average Distance(d) (m)
"Low"	≤10	≤5	≤35
"Med"	>10 and ≤20	>5 and ≤10	>35 and ≤70
"High"	>20 and ≤30	>10 and ≤15	>70 and ≤105

The validation of the proposed fuzzy controller 'FBRS' was done in MATLAB by selecting various values of input parameters used in IAODV-F and calculating the selection index of the path based on fuzzy values obtained on applying the fuzzy rules. Two boundary cases are presented here as shown in Figure 4a & 4b. In case-1, value of £=6 packets, d=15m and $\boldsymbol{\mu}$ =2.8 m/sec. In case 2, £=27 packets, d=86m and $\boldsymbol{\mu}$ =13.1 m/sec. Interface engine maps these values onto rule-base and provide selection index values 2.53 and 0.492 respectively on a scale of 3. This validates our FBRS as selection index is high for more stable and less energy intensive path as compared to less stable and high energy consuming path.

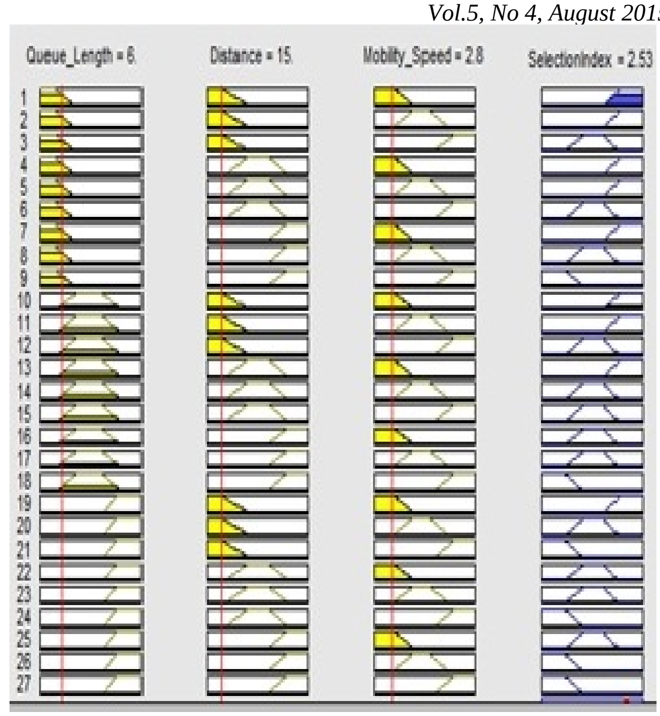

Figure-4a Application of aggregation method case-1

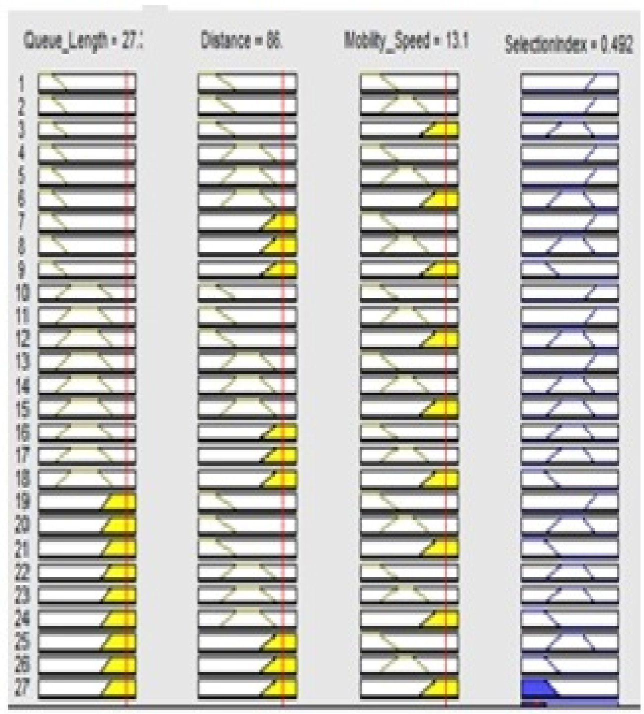

Figure-4b Application of aggregation method case-2

The nonlinear mapping from input to output implemented by the FBRS fuzzy controller is called control surface. This mapping can be visualized by a nonlinear surface a plot, where the controller's output is plotted against its inputs. Figure 5 shows such a control surface for the FBRS with three dimensions. The rippled surface is created by the fuzzy rules and the membership functions. The output selection index is an interpolation of the effects of the rules that are activated at current instances.

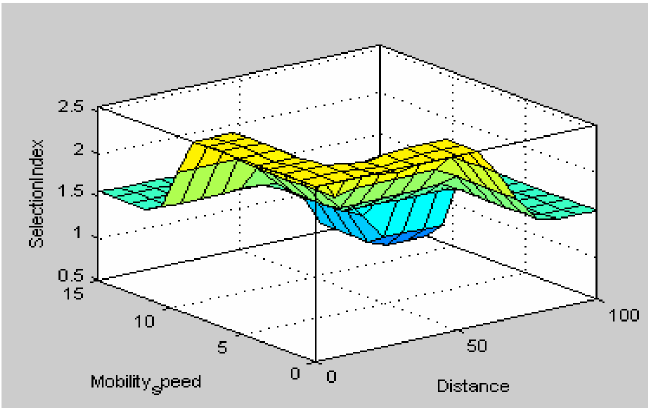

Figure-5 Nonlinear control surface of ABRS for designed fuzzy rules

I. Performance Evaluation

The performance of the proposed protocol IAOMDV-F is determined and compared with AODV, AOMDV and AOMDV-F. The performance metrics' used in this study are - end-to-end delay, throughput, packet delivery rate and energy consumption.

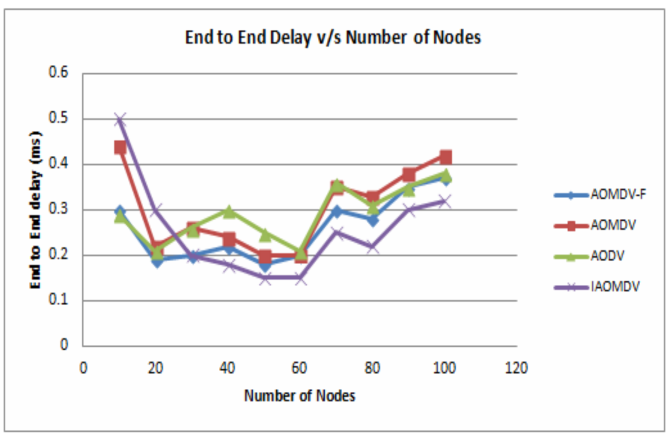

Figure 6. End to end delay with number of nodes

Figure 6 shows, the end to end delay decreases with increase in number of node for the proposed IAOMDV-F protocol and its performance is significantly better than other protocols when nodes are more than 25 and it is comparable when numbers of nodes are small. It is because the protocol selects a path with smaller values of average distance, average queue length and average speed. This gives a path which requires less waiting, transmission, discovery, and maintenance time and with decreased probability of link failure. The poor performance at less number of nodes is evident as the area of the network is fixed giving large average distance of the selected path and high average value of queue length due to less number of available paths for same load.

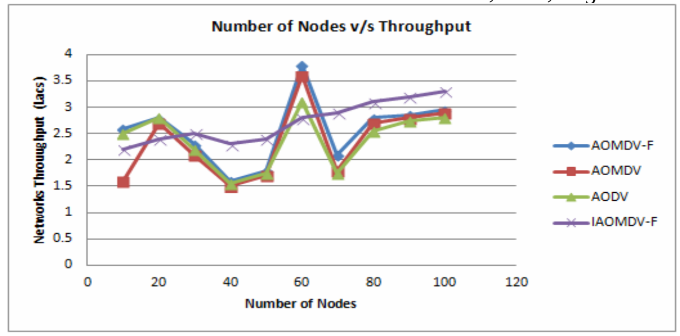

Figure-7 Throughput with number of nodes

IAOMDV-F also shows better performance in terms of throughput as shown in Figure 7. This is attributed to the selection of more stable path by proposed fuzzy controller FBRS with reduced end to end delay and retransmission apart from the reasons mentioned above. Here also throughput increases with number of nodes when number of nodes is more than 30.

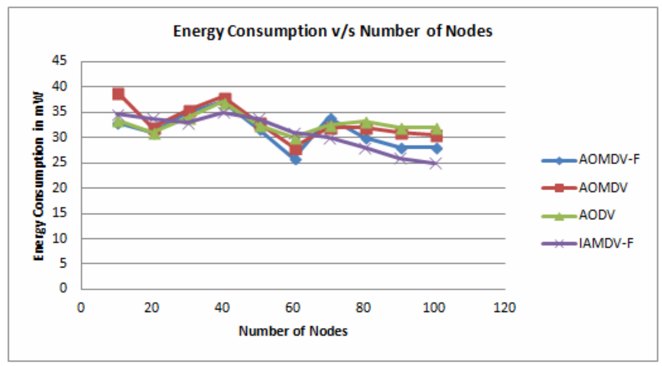

Figure-8 Energy Consumption with number of nodes

The energy consumption in IAOMDV-F protocol is also significantly reduced for number of nodes more then 35 as shown in Figure 8 and Figure 9. It is due to the selection of a path with small average distance which reduces the transmission energy; minimum queue length which reduces the processing/retransmission energy and less average speed of nodes which reduce energy consumption to re-discover and maintenance the path.

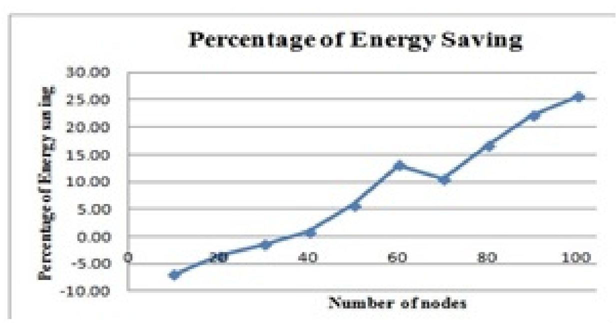

Figure-9 Percentage of Energy Saving in IAOMDV-F

The percentage of energy saving in IAOMDV-F protocol in comparison to the AOMDV-F increases linearly with number of nodes. The energy consumption in IAOMDV-F is more if numbers of nodes are less than 40. The maximum energy saving is nearly 25% as compared to AOMDV-F at nearly 100 nodes.

IV. CONCLUSIONS

In this work, an energy efficient and stable routing protocol IAOMDV-F based on fuzzy logic was designed. Although, the proposed protocol is based on AOMDV but main contribution is the new fuzzy controller FBRS imbibed, which resulted significant improvement in its performance. The proposed protocol was compared with AODV, AOMDV and AOMDV-F and found to outperform these protocols. The proposed new fuzzy based controller FBRS offers significant improvements in optimizing the energy consumption and stability of the route, making the proposed protocol not only energy efficient but more stable too. The proposed protocol provides more energy saving in large network than small size network when compare to the fuzzy based routing protocol AOMDV-F. The energy saving is nearly 25% in network having about 100 nodes.

REFERENCES

[1] C. E. Perkins, E. M. Belding-Royer, S. R. Das, Ad hoc On-Demand Distance Vector (AODV) Routing, Internet Draft IETF Mobile Ad hoc Networks (MANET) Working Group, pp.125-150, 2003.

[2] M. Tarique, K. E. Tape, S. Adibi, S. Erfani, Survey of Multipath Routing Protocols for Mobile Ad Hoc Networks, Journal of Networks and Computer Applications, Volume 32, Issue 6, pp. 1125-1143, Nov2009.

[3] B. David, J. David A. Maltz, Y. C. Hu, The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR), Internet Draft, IETF Mobile Ad hoc Networks (MANET) Working Group, pp.1-108, 2003.

[4] A. L. Soo, C. E. Tan, K. M. Tay, Fuzzy Multiple Metrics Link Assessment for Routing in Mobile Ad-hoc Network, In AIP Conference Proceedings, pp. 1337-1346, June, 2011.

[5] F. A. Larki, J. M. Seyed and A. Harounabadi, Increased Longevity of Wireless Ad hoc Network through Fuzzy System, Decision Science Letters-3, pp.1-9, 2014.

[6] J. P. Shew, K. Y. Hsieh, Y. K. Cheng, Distributed Transmission Power Control Algorithm for Wireless Sensor Networks, Journal of Information Science and Engineering, pp.1447-1463, 2009.

[7] A. A. Hemyari, M. Ismail, R. Hassan, S. Saeed, Improving Link Stability of Multicasting Routing Protocol in Manets, Journal of Theoretical and Applied Information Technology, 10th September, 2013. Vol. 55, No.1, ISSN: 1992-8645, pp. 109-116, 2013.

[8] S. Sheeja, R. V. Pujeri, Cross Layer based Congestion Control Scheme for Mobile Ad hoc Networks, International Journal of Computer Applications (0975 – 8887), Volume 67– No.9, pp. 60-67, April 2013.

[9] S. A. Kulkarni, G. R. Rao, Quality of Service Issues for Reinforcement Learning Based Routing Algorithm for Ad-Hoc Networks, Journal of Computing and Information Technology - CIT 20, doi:10.2498/cit.1002080, pp. 247–256, 1012.

[10] J. A. Torkestani, M. R. Meybodi, A Link Stability-based Multicast Routing Protocol for Wireless Mobile Ad Hoc Networks, Journal of Networks and Computer Applications, Volume 34, pp. 1429-1440, Jan 2011.

[11] B. Sun, C. Gui, Q. Zhang, H. Chen, Fuzzy Controller Based QoS Routing Algorithm with a Multiclass Scheme for MANET", Int. J. of Computers, Communications & Control, ISSN 1841-9836, E-ISSN 1841-9844, Vol. IV, pp. 427-438, 2009.

[12] C. Wan, S. B. Eisenman, A. T. Campbell, Energy-Efficient Congestion Detection and Avoidance in Sensor Networks , ACM Transactions on Sensor Networks, Vol. 7, No. 4, Article 32, 2011, pp.32.1-32.31.

[13] B. Chen, C. H. Chang, Mobility Impact on Energy Conservation of Ad Hoc Routing Protocols", ,MTS, U.S.A., pp.1-7.

[14] E. Amiri, H. Keshavarz, M. Alizadeh, M. Zamani, T. Khodadadi, Energy Efficient Routing in Wireless Sensor Networks Based on Fuzzy Ant Colony Optimization, International Journal of Distributed Sensor Networks, Article ID 768936, pp. 1-17, 2014.

[15] B. Christian, R. Giovanni, S. Paolo, The node Distribution of the Random Waypoint Mobility Model for Wireless Ad hoc Networks, IEEE Transactions on mobile computing, 2(3), pp. 257-269, July 2003.

[16] S. Gowrishankar, T. G. Basavaraju, S. K. Sarkar, Simulation Based Overhead Analysis of AOMDV, TORA and OLSR in MANET Using Various Energy Models, Proceedings of the World Congress on Engineering and Computer Science, Vol-I, WCECS 2010, San Francisco, USA, 2010.

[17] K. Fall, K. Varadhan, The ns Manual (formerly ns Notes and Documentation), The VINT Project, UC Berkeley, LBL, USC/ISI, and Xerox PARC, February 11, 2007.

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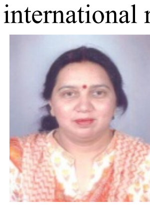

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