FEA-OLSR: An Adaptive Energy Aware Routing Protocol for MANETs Using Zero-Order Sugeno Fuzzy System

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Abstract

Optimized Link State Routing (OLSR) is a standard proactive routing protocol for Mobile Ad-hoc NETworks (MANETs). In this paper, we use a zero-order Sugeno Fuzzy Logic System (FLS) for adjusting the willingness parameter in OLSR protocol. Decisions made at each mobile node by the FLS take into account its remaining energy and its expected residual lifetime. Simulation study revealed that the proposed protocol Fuzzy Energy-Aware OLSR (FEA-OLSR) is more energy efficient than EE-OLSR a heuristic based energy-aware variant of OLSR.

Keywords: OLSR, MANETs, Zero Order Sugeno Fuzzy System, Willingness Parameter, Energy-Aware Routing.

1. Introduction

Mobile Ad-hoc NETwork (MANET) is a collection of mobile wireless devices that are able to communicate without any pre-established network infrastructure. To ensure routing service, all nodes in MANET cooperate in forwarding neighbors traffic until reaching its intended destination. Traditional routing protocols built for wired networks could not be directly used in MANETs. This is because MANETs are characterized by many challenging features including poor wireless-links quality, nodes mobility, limited bandwidth and energy-resources. This is in addition to the lack of any central control. Due to the above-mentioned features, the design of specific routing solutions for MANETs has made the main focus of almost all researchers' contributions in the field of mobile ad hoc networking [1].

Routing protocols for MANETs could be classified as either reactive or proactive [2]. A reactive routing protocol does not calculate routes beforehand, but only when data traffic is present for routing. This is done via a route discovery procedure which is initiated by the source node. This latter broadcasts a Route REQuest (RREQ) packet to all its one-hop neighbors. Each neighboring node rebroadcasts again the received RREQ. The same operation is repeated until that destination node is reached. In answer, the destination node generates a Route REPlay (RREP) packet. This approach presents the disadvantage of a long response time in comparison to its proactive counterpart.

Proactive routing protocols, also known as table driven, are modifications of traditional link-state and distance-vector based routing protocols for wired networks. They are built on periodic exchange of routing information. This is in the aim of making routing tables up to date all the time. Moreover, routes are maintained toward all possible destinations. Hence, routing could start immediately whenever data traffic is present. However, the main drawback of proactive routing is the great amount of generated routing overhead. This leads to the wastage of network-bandwidth and nodes-energy.

One interesting proposals to reduce the generated routing overhead by the proactive approach is the concept of Multi-Point Relays (MPRs) introduced in the OLSR protocol [3]. The key idea is to limit the number of retransmissions required for a node to flood a packet in the entire network. For this purpose, each node elects a subset of its one-hop neighbors to be responsible of forwarding its broadcasted packets. Those nodes are called MPRs. Certainly such a solution also contributes to minimization of the overall network energy consumption. However, as a non-uniform routing protocol, OLSR overuses the energy of the MPRs nodes. In fact, energy is drained more quickly in MPRs nodes than in no-MPRs ones. Therefore, it is a mandatory to rethink energy aware versions for the OLSR protocol. Particularly, maximum lifetime routing approach that avoids nodes with poor energy profiles should be adopted.

In this paper, we propose an energy-aware OLSR variant built on a zero order Sugeno fuzzy logic system. To the best of our knowledge, this work is the first one in the literature to use a FLS for adjusting the willingness parameter in OLSR protocol according to nodes energy profiles. The reminder of this paper is organized as follows. Section 2 reviews the related literature to maximum lifetime routing with OLSR. Section 3 gives an insight on Fuzzy Logic application for adaptive routing and particularly on its application for energy-aware routing. Section 4 describes the OLSR protocol in a greater detail. EE-OLSR, a heuristic based energy-aware OLSR, is presented in section 5. Our proposed protocol FEA-OLSR is introduced in section 6. Simulation results are reported and discussed in section 7. Finally, section 8 concludes the paper and draws some future research directions.

2. Related Works

The literature counts many research works in the area of maximum-lifetime routing for OLSR protocol. As shown in Table1, we could distinguish two main families of solutions. The first one seeks to make energy aware selection of MPRs nodes. The second one focalizes on the choice of low energy-cost paths for routing. A combination of both solutions is also feasible.

Table 1: Some Related Works to Maximum-Lifetime Routing with OLSR

	Energy-Aware MPRs Selection	Low Energy-Cost path
Ghanem et.al. [4]	✓	
Wardi et.al. [5]	✓	
Benslimane et.al. [6]	✓	✓
Guo et.al. [7]		✓
Mahfoudh et.al. [8]	✓	✓
De Rango et.al. [9]	✓	
Lakrami et.al.[10]	✓	
Guo et.al. [11]		✓

Very intuitively, Ghanem et al. [4] proposed to use the residual energy as a criterion for choosing MPRs nodes. In addition to the residual energy, Wardi et al. [5] suggested considering the reachability and the degree of one-hop neighbor nodes. To select paths with maximum bottleneck residual energy level, Benslimane et al. [6] combined energy-aware MPR selection with an energy aware path determination algorithm. Guo et al. [7] modified the path computing algorithm in OLSR. Paths are selected according to the residual energy level of intermediate nodes. Mahfoudh et al. [8] proposed a variant of OLSR where MPR selection and path calculation is determined by both a node’s residual energy level and its number of neighbors. De-Rango et al. [9] modified the setting method of the willingness parameter in OLSR. This is by introducing the battery power and the expected residual lifetime. In the same context, Lakrami et al. [10] suggested considering energy and mobility factors. Guo et al. [11] developed a new energy aware metric for routing with OLSR. This metric takes into account both nodes power consumption and their residual energy.

3. Adaptive Routing in MANETs Using Fuzzy Logic Systems

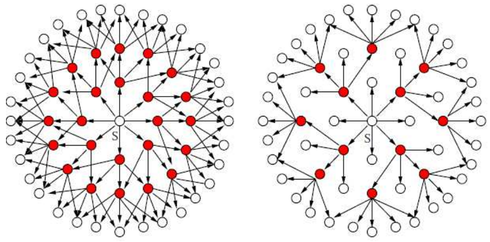
An important feature in designing routing protocols for MANETs is *adaptivity*. An adaptive routing protocol could be defined as a routing protocol that is able to change its routing policy online according to current network conditions [12]. In fact, in MANETs, routing information is usually inaccurate and incomplete due to their dynamic and distributed nature. To deal with such imprecision, let us say *fuzziness*, the use of Fuzzy Logic Systems has been proven to be an advantageous solution.

Fuzzy Logic Sytems (FLS) proposed in the context of MANETs adaptive routing could be classified according to their optimization goal into [13]: FLS for routes costs estimation, QoS-based routing, energy-aware routing, position-based routing, zone-based routing, clustering, parameters configuration, and routes local repair. Since the FLS proposed in this paper subscribes in the energy aware routing area, in what follows, we focalize our attention on related works to energy-aware routing based on fuzzy logic.

El-Hajj et al. [14] proposed a fuzzy based hierarchical energy efficient routing scheme (FEER) for large scale mobile ad-hoc networks. At each node, three inputs for the fuzzy controller are considered, namely: residual energy, traffic, and mobility. The inferred value gives an indication on node importance which is exploited in cluster-heads election. To evaluate paths cost in AODV routing protocol, Ali et al. [15] proposed that each node implements a fuzzy controller which takes as inputs: number of hops, packet queue occupancy, and remaining energy. Abirami et al.[16] proposed a FLS to be used by destination nodes to choose energy efficient paths. The FLS inputs are battery cost and power consumption of discovered paths via the conventional route discovery procedure of a reactive routing protocol. Dutta et al. [17] proposed a fuzzy controlled power-aware multicast routing (FPMR) protocol. Each node in the network implements two fuzzy controllers: EINS (Eligible Intermediate Node Selector) and RPE (Route Performance Evaluator). The EINS inputs are the node residual energy, the minimum required energy to forward all multicast packets through the node, node link stability with its predecessors in the multicast communication paths and number of established paths multicast members. The EINS output indicates the node eligibility to act as a router in a multicast path. The RPE estimates the quality of a multicast route. For this purpose, it uses as input parameters: hop count, number of eligible intermediate nodes in it and number of multicast members present in it as an intermediate node. Hiremath et al. [18] proposed an adaptive energy efficient reactive routing protocol. The proposed protocol is based on a fuzzy thresholding of residual energy of nodes participating in the route discovery procedure. A node forwards the received RREQ if and only if its residual energy is higher than the threshold value included in the RREQ. If the node decides to forward the RREQ then it calculates a new fuzzy threshold according to its neighbors' residual energies. It includes this threshold in the RREQ and rebroadcasted it again.

4. The Optimized Link State Routing Protocol

OLSR first presented in [3] and then standardized in IETF RFC3626 in 2003 [19], is a proactive link state routing protocol built on the concept of MPRs. In OLSR, each node chooses a subset of its one hop neighbors to forward its packets in case of broadcasts. Therefore, packets-flooding in the entire network is achieved with minimal amount of retransmissions (see Fig 1.). The MPR set of a node is a minimal subset of its one-hop neighbors that cover all its 2 hop neighbors.



Colored-nodes retransmit the broadcasted packets
(a) Conventional flooding (b) MPRs mechanism

Fig. 1 Flooding optimization by Multi-Point Relays Technique

In OLSR, each node broadcasts Hello messages in which it indicates the state of its links. Thank to Hello messages exchange, a node could build both its neighbors list and MPR-selector set. A node which has chosen its 1-hop neighbor, node X, as its multipoint relay, is called a multipoint relay selector of node X [19]. Moreover, each node broadcasts periodically TC (Topology Control) messages containing the list of it MPR- Selector. OLSR nodes exploit TC messages to construct a Topology Table. This latter with neighbor list are used to construct the Routing Table. It is worth mentioning that OLSR is better adapted for high density networks. However, for a network with low density, each neighbor becomes MPR and OLSR performs as any ordinary link state routing protocol [20].

In OLSR, each node maintains a willingness variable that reflects its ability to act as a router (i.e. as a MPR) for its neighbors. The willingness value is piggybacked in Hello packets (see Fig.2). However, in the standard implementation of OLSR this variable is set to a default value. In other words, it is not exploited.

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Reserved             |     Htime     |  Willingness  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Link Code   |   Reserved    |       Link Message Size       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Neighbor Interface Address                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Neighbor Interface Address                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                             . . .                             :
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Fig. 2 The OLSR Hello Message Format [19]

5. Energy-Efficient OLSR (EE-OLSR)

De Rango et al. [9] have proposed a heuristic to set the willingness value in OLSR Protocol. Each node according to its residual battery and predicted lifetime decides to attribute a low (WILL_LOW), a default (WILL_DEFAULT) or a high (WILL_HIGH) value to its willingness variable. The proposed heuristic is depicted in Fig. 3. Note that the predicted lifetime in seconds at time step t, *Lifetime*, is calculated as in Eq.1:

$$\text{Lifetime} = \frac{\text{RE}_\text{t}}{\text{DRate}_\text{t}} \qquad (1)$$

RE_t and DRate_t denote, respectively, the residual energy and the energy drain rate at time step t . DRate_t is computed using the exponential moving average method as proposed in [21]. To measure the energy drain rate per second, each node monitors its energy consumption during a T seconds sampling interval.

$$\text{DRate}_\text{t} = \alpha \times \text{DRate}_{\text{t}-1} + (1-\alpha) \times \text{DRate}_\text{Sample} \qquad (2)$$

In Eq.2, $\text{DRate}_{\text{t}-1}$ indicates the drain rate calculated in the previous interval, whereas $\text{DRate}_\text{Sample}$ is the newly observed energy drain rate value.

```
Double lifetime=65535;/*set to a maximal value*/
Double battery = RE/ INITIAL_ENERGY;
if (DRate != 0.0) {lifetime = RE/ DRate; }
willingness= WILL_DEFAULT;
 if (lifetime< 10.0) {willingness= WILL_LOW;}
else{
    if ((battery < 0.1) && (lifetime < 100.0)){
         willingness= WILL_LOW;}
      else{
      if ((battery > 0.1) && (lifetime > 100.0)){
            willingness= WILL_HIGH;}}}
```

Fig. 3 The willingness Setting Heuristic of EE-OLSR [9].

In EE-OLSR implementation, less than 10% of residual battery capacity is considered as low value. Moreover, less than 10 seconds of predicted lifetime is considered to be short, whereas more than 100 seconds is long lifetime. The authors claim that their willingness setting policy contributes in a better load balancing where low battery-charged nodes are avoided in comparison to the standard OLSR.

6. The Proposed Fuzzy-based Energy Aware OLSR (FEA-OLSR)

To compute the willingness parameter, in FEA-OLSR, each node uses a FLS. In this latter, the Remaining Energy, RE, and the Expected Residual Lifetime, ERL, are the FLS inputs. The linguistic terms used to qualify them are: “Low” and “High”. Note that all the input membership functions are Trapezoidal. A Trapezoidal membership function, $\mu(x)$, is defined by Eq.3. The membership functions associated to RE and ERL inputs are graphically presented in Figures 4 and 5.

$$\mu(x) = \begin{cases} \frac{x-a}{b-a} & if\ x \in [a,b] \\ 1 & if\ x \in [b,c] \\ \frac{d-x}{d-c} & if\ x \in [c,d] \\ 0 & otherwise \end{cases} \tag{3}$$

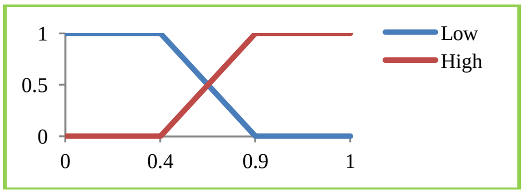

Fig. 4 Membership Function for RE Input

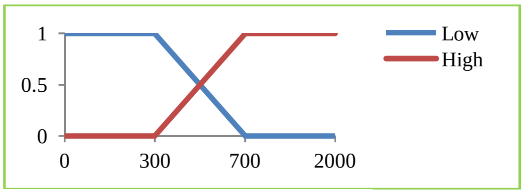

Fig. 5 Membership Function for ERL Input

The output of the fuzzy logic system is the node willingness to be chosen as an MPR node. To qualify the output, the terms “WILL_Low”, “WILL_Default” and “WILL_High” are used. It is worthwhile to mention that the output membership function is constant singletons as illustrated in Fig. 6.

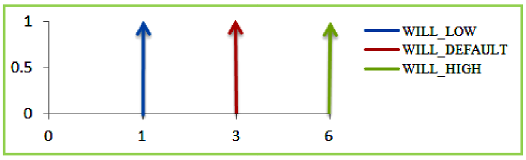

Fig. 6 Membership function for Willingness Output

The inference engine for the fuzzy system follows a Zero-order Sugeno fuzzy model. The Sugeno fuzzy model (also known as TSK model) was proposed by Takagi, Sugeno and Kang in [22]. A typical inference rule in a Sugeno fuzzy model has the following form: $\boldsymbol{If\ Input1} = \boldsymbol{x\ and\ Input2} = \boldsymbol{y\ Then\ Output\ z = ax + by + c}$

For a zero-order Sugeno model, the output z is a constant (i.e. $a = b = 0$). The output z_i of each rule is weighted by the firing strength w_i of the rule. The final output of the system is the weighted average of all rule outputs, computed as shown in Eq. 4. N denotes the number of fuzzy rules. The proposed fuzzy-rules base is introduced in Table 2.

$$Final\ output = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \tag{4}$$

Where:

$$w_i = MIN(\mu(RE), \mu(ERL)) \tag{5}$$

Table2: Fuzzy Rules Base

FLS Inputs		FLS Output
RE	**ERL**	**Node Willingness**
LOW	LOW	WILL_LOW
LOW	High	WILL_DEFAULT
High	LOW	WILL_LOW
High	High	WILL_HIGH

7. Simulation Study

We built EE-OLSR and FEA-OLSR on top of UM-OLSR [23] which is an OLSR implementation for the NS-2 simulator [24]. In this simulation study, we are interested in measuring the following performance metrics: i) *Time to Half Nodes Energy Depletion* (THNED) in Seconds: The time at which the network sees 50% of its nodes exhausting all their batteries; ii) *Average Data-Packets Delivery Fraction* (PDF): The ratio of successfully received data packets by destination nodes to those generated by source nodes; and finally iii) *Average end-to-end Delay* (Delay) in Seconds: The average time that takes a data packet to go from the source node to the destination node.

Table 3: Simulation Parameters setting

Simulation Parameter	Value
Network Scale	800m x 800m
Simulation Time	900s
Number of nodes	50
Mobility Model	Random Way Point
Maximum Nodes Velocity	5m/s

Pause Time	0s
Traffic Type	CBR
Connections Number	10, 20
Packets Transmission Rate	4 Packets/s
Initial energy	10 Joules
Transmission Power	0.6 Watt
Reception Power	0.3 Watt
The weighting factor α	0.3
T Sampling Interval	5s

In the simulation experiments we evaluate the protocols performances under two traffic scenarios, namely: low and high traffic-load. Briefly, simulation parameters were set as illustrated in Table 3. The obtained results are presented in Tables 4, 5 and 6 where each result is the average of 20 simulation runs with randomly generated mobility scenarios.

Both EE-OLSR and FEA-OLSR belong to the Maximum-Lifetime routing family. Hence, their main objective is to extend network lifetime. Many definitions could be found in the literature for the concept of network lifetime. For example: time to first node energy depletion, time to a certain amount of nodes energy depletion or time to network partition, etc. In this paper, we have chosen the second definition by measuring the time to 50% nodes energy depletion.

Table 4: THNED with variable number of traffic connections

Number of Connections	10	20
EE-OLSR	202.2044452	83.64942645
FEA-OLSR	**207.7831096**	**83.83367985**

The obtained THNED results show that FEA-OLSR ensures a longer network lifetime in comparison to EE-OLSR. This confirms the efficiency of the proposed FLS with regard to the heuristic implemented by EE-OLSR. However, as could be easily observed, increasing traffic connections has a negative impact on network lifetime. This is because nodes consume more quickly their energies by forwarding more data traffic. This also explains why the difference between the achieved THNED results, for FEA-OLSR and EE-OLSR, becomes less important under the high traffic scenario.

Table 5: PDF with variable number of traffic connections

Number of Connections	10	20
EE-OLSR	89.851705	42.7322345
FEA-OLSR	**90.03226**	**42.9269675**

Economizing energy should never come at the cost of data packets dropping. An energy efficient routing protocol is one that achieves a good tradeoff between maximizing packets delivery fraction and maximizing network lifetime. In terms of PDF metric, FEA-OLSR has outperformed EE-OLSR protocol. This indicates that FEA-OLSR is really more energy-efficient than EE-OLSR.

Unfortunately, network congestion has incurred a reduction in the PDF metric for both protocols. This could be explained as follows. On one hand, congested nodes systematically drop any new received data packets; on the other hand, high traffic load is coupled with a high interference level.

Table 6: Delay with variable number of traffic Connections

Number of Connections	10	20
EE-OLSR	0.019288622	0.022978025
FEA-OLSR	**0.018312655**	**0.02246488**

As shown in Table 6, FEA-OLSR has marked the lowest delay in both low and high traffic scenarios. In fact, this is a suitable feature for real time applications that requires a short end-to-end delay. However, under high traffic conditions, data-packets spend longer time in the queuing buffers of congested nodes. This explains the deterioration of the Delay metric under high traffic scenario for both protocols.

8. Conclusions

In this paper, we tackled the problem of adaptive energy-efficient routing in MANETs. Our focus was on exploiting the potential of Fuzzy Logic reasoning in overcoming the issue of available routing information uncertainty in MANETs. Particularly, we addressed the problem of OLSR willingness-parameter setting according to nodes energy-profiles using a Fuzzy Logic Zero-Order Sugeno system. Simulation results have confirmed the outperformance of FEA-OLSR in comparison to EE-OLSR an energy-aware heuristic based variant of OLSR. We expect that coupling the proposed FLS for MPRs energy-aware selection with an energy-efficient route computing strategy will contribute to better performances. To enhance network adaptivity in face of variable traffic conditions, we are currently working on an extension to the presented FLS.

Adaptive routing in MANETs is a very challenging issue. Dealing with the uncertainty of available routing information constitutes only one aspect of the problem. We believe that nodes in MANETs should be also able to learn how to make adaptive routing decisions online. As future research perspective, we plan to investigate a combination of Fuzzy reasoning with a machine learning technique.

References

[1] A. Boukerche, "Algorithms and Protocols for Wireless and Mobile Ad Hoc Networks", John Wiley & Sons Inc, Ottawa, Canada, 2009.

[2] A. Boukerche, B. Turgut, N. Aydin , M. Z. Ahmad , L. Bölöni and D.Turgut, "Routing protocols in ad hoc networks: A survey", Computer Networks,ELSEVIER, Vol.55, 2011, pp. 3032- 3080.

[3] P. Jacquet, P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum and L. Viennot, "Optimized link state routing protocol for ad hoc networks", in IEEE INMIC, 2001.

[4] N. Ghanem, "New energy saving mechanisms for mobile ad-hoc networks using OLSR" in the 2nd ACM International Workshop on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks, 2005, pp. 273–274.

[5] Wardi , K. Hirata and Y. Higami , S. Kobayashi, " REOLSR: Residual Energy-Based OLSR Protocol in Mobile Ad Hoc Networks", IJMT Vol.1, 2011, pp.93-97.

[6] A. Benslimane, R. El Khoury, R. El Azouzi and S. Pierret, "Energy power-aware routing in OLSR protocol" in the First Mobile Computing and Wireless Communication International Conference, 2006, pp. 14–19.

[7] Z. Guo and B. Malakooti, "Energy aware proactive MANET routing with prediction on energy consumption", in the International Conference on Wireless Algorithms, Systems and Applications, 2007, pp. 287–293.

[8] S. Mahfoudh and P. Minet, "EOLSR: an energy efficient routing protocol in wireless ad hoc sensor networks", Journal of Interconnection Networks Vol.9 , 2008, pp. 389–408.

[9] F. De Rango, M. Fotino, and S. Marano, "EE-OLSR: Energy Efficient OLSR Routing Protocol for Mobile Ad Hoc Networks", in Military Communication Conference (MILCOM), 2008, pp. 1-7.

[10] F.Lakrami and N. Elkamoun, *" Energy and mobility in OLSR routing protocol"*,in Journal of Selected Areas in Telecommunications (JSAT), 2012.

[11] Z. Guo , S. Malakooti , S. Sheikh, C. Al-Najjar, M. Lehman and B. Malakooti, "Energy aware proactive optimized link state routing in mobile ad-hoc networks", Journal of Applied Mathematical Modelling, vol.35, 2011, pp. 4715 - 4729.

[12] F. Ducatelle, G.Di Caro and L.M. Gambardella, "Principles and applications of swarm intelligence for adaptive routing in telecommunications networks", in Swarm Intelligence journal, 2009.

[13] E. Natsheh, " A Survey on Fuzzy Reasoning Applications for Routing Protocols in Wireless Ad Hoc Networks", in IJBDCN , Vol.4,2008, pp. 22-37.

[14] W. El-Hajj, D. Kountanis, A. Al-Fuqaha and M. Guizani, "A fuzzybased hierarchical energy efficient routing protocol for large scale mobile ad hoc networks (feer) ", in IEEE ICC,2006.

[15] A. A. Ali and T. O. Fahad, "Fuzzy Energy based Routing Protocol for MANET" , in International Journal of Computer Applications Vol. 46, 2012, pp.38-40.

[16] S.Abirami, R.Dhanasekaran and V.Bhanumathi, "A Balanced Approach for Power Aware Routing in MANET using Fuzzy Logic" International Conference on Recent Trends in Computational Methods, Communication and Controls , 2012.

[17] P. Dutta and A. Banerjee, "Fuzzy-controlled Power-aware Multicast Routing (FPMR) For Mobile Ad Hoc Networks", in Procedia Technology Vol.4, 2012, pp.38 – 49.

[18] P.S.Hiremath and S. M.Joshi, "Energy Efficient Routing Protocol with Adaptive Fuzzy Threshold Energy for MANETs" in International Journal of Computer Networks and Wireless Communications (IJCNWC), Vol.2, 2012,pp. 402- 407.

[19] T. Clausen, and P. Jacquet, " Optimized Link State Routing Protocol (OLSR) ", RFC 3626, IETF : The Internet Engineering Task Force, 2003, <http ://www.ietf.org>.

[20] C. Liu, J. Kaiser, "A Survey of Mobile Ad Hoc network Routing Protocols", Technical Report (Nr. 2003-08) University of Ulm, Germany, 2003.

[21] D. Kim, J.-J. Garcia-Luna-Aceves, K. Obraczka, J.-C Cano and P. Manzoni, "Power-aware routing based on the energy PDFain rate for mobile ad hoc networks", in 11th Int. Conf. on Computer Communications and Networks, 2002,pp. 565 – 569.

[22] Takagi, T. and Sugeno, M.: Fuzzy identification of systems and its applications to modeling and control", in IEEE transactions on Systems, Man, and Cybernetics VOL 15, 1985, pp. 116-132.

[23] F.J. Ros, "UM-OLSR, an implementation of the OLSR (Optimized Link State Routing) protocol for the ns-2 network simulator", <http:// masimum.dif.um.es/Software:UM-OLSR>.

[24] The network simulator, NS version 2, <http://www.isi.edu/nsnam/ns/>.

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