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.

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

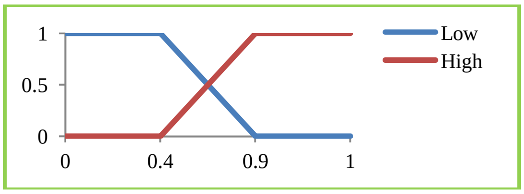

Fig. 4 Membership Function for RE Input

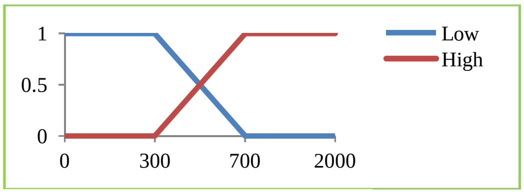

Fig. 5 Membership Function for ERL Input

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.

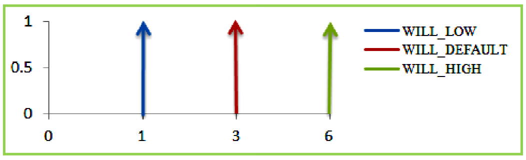

Fig. 6 Membership function for Willingness Output

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: $\boldsymbol{If\ Input1} = \boldsymbol{x\ and\ Input2} = \boldsymbol{y\ Then\ Output\ z} = \boldsymbol{ax} + \boldsymbol{by} + \boldsymbol{c}$

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.

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

Where:

$$w_i = MIN(\mu(RE), \mu(ERL)) \qquad (5)$$

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/>.

Saloua CHETTIBI received her MSc degree in computer sciences from University Mentouri of Constantine, Algeria, in 2008. Since 2009, she joined the SCAL Team within MISC Laboratory at University Constantine 2, to prepare her PHD thesis. Actually she is an associate Professor at University of Jijel, Algeria. Her research topics include soft computing and Mobile ad-hoc networking.

Salim CHIKHI received his MSc degree in computer systems from University Mentouri of Constantine, Algeria, in collaboration with Glasgow University, UK, in 1993. He received his PhD degree in computer science from University Mentouri of Constantine, Algeria in 2005. Currently, he is a full professor at the University Constantine 2, Algeria. He is leader of the team "Soft Computing and Artificial Life" within MISC laboratory (Modeling and Implementation of Complex Systems). His research areas include soft computing and artificial life techniques and their applications to real life problems and their optimization.