# Multi Path Routing Based Energy-Efficient for Extending Mobile Wireless Sensor Networks Lifetime

Fatiha Djemili Tolba[1] and Pascal Lorenz[2]
[1] Department of Computer Science, Badji Mokhtar-Annaba University, P.O. Box 12, 23000. Annaba, Algeria
[2] GRTC-Colmar, University of Haute Alsace, 68008. Colmar, France
Email: fatiha.djemili@univ-annaba.dz; lorenz@ieee.org

***Abstract***—Energy is a challenge in wireless sensor networks because of its effects on several fundamental functions of the network, such as data collection, communication and routing. Therefore, energy efficiency is a fundamental factor determining the performance and lifetime of the network. For this, the saving energy achieved in the WSN have led to many research projects on various aspects such as energy efficiency, energy management or energy control. In order to complete the data collection process, better multipath routing, which balances the traffic load is an additional challenge for WSN. With this in mind, we are developing energy efficiency and traffic load balanced strategies for the multipath routing algorithm. We first describe the principle of the proposed algorithm based on several metrics. Simulations were performed to check the performance of the proposed algorithm. The proposed algorithm QLBR achieves an energy gain of 11% compared to the LBR algorithm and extended network lifetime by about 9%.

***Index Terms***—Mobile wireless sensor network, routing, energy, load balancing, network lifetime

## I. Introduction

The rapid evolution of wireless communication technology has resulted in the emergence of tiny, interconnected electromechanical systems, known as Wireless Sensor Networks (WSN). The WSNs have been acquired in a very wide range of applications (healthcare, industry: manufacturing and smart grids, transportation systems, public safety and military systems, environment and agriculture, underground and underwater sensor networks). As a result, each application requires well-defined criteria for implementation, such as scalability, coverage, latency, QoS, security, mobility and robustness. The main requirement common to all applications is to extend the network lifetime as long as possible. For example, over the last ten years, several researches have been conducted to save energy in WSNs by using different techniques: radio communication, data reduction, sleep/wakeup schemes, energy-efficient routing and battery repletion [1].

In the energy-efficient routing category, there are numerous routing protocols. Most multi-hop protocols take into account only one criterion among the number of hops, energy, link quality and traffic load or mobility, which can lead to congestion, exhaustion of energy and unstable road. These protocols are based on the use of simple routing criteria and routing based on the minimum number of hops. However, if the number of communications increases, the principle of the shortest path is therefore not the optimal criterion for choosing routes. In addition, if the node participating in the path creation process has a very low energy, it can be disconnected very quickly. Hence, the node that has the load too high decreases the quality of service by losing many packets, especially the nodes closest to the sink. This can have a detrimental effect on the network lifetime. To solve this problem, the combination of routing criteria is the solution for selecting the most optimal paths. In this case, it is preferable to implement a multi-criteria algorithm having a significant effect on the connectivity and the network lifetime.

In this paper, we focus on energy-efficient routing strategies because it represents an additional charge that can significantly drain energy reserves [2]. Our aim is to provide a multi-path routing to improve the reliability of mobile wireless sensor networks. Thus, one of the main objectives of multi-path routing algorithm is to coordinate the node of network by choosing the best qualities of nodes. The choice of the node takes into account several critical criteria to assure the delivery of the parquets, while maximizing the network lifetime and balancing the load traffic. The criteria managed by our algorithm are residual energy, node mobility, traffic load and links quality developed among nodes. This contribute to ensure reliable routing and stable routes for mobile wireless sensor networks.

The remainder of this paper is organized as follows. The following section highlights some related works. In Section 3, we describe the principal of proposed routing algorithm and the metrics used to achieve a trade-off between load balancing and energy efficiency. The results of the simulation are presented in section 4.

## II. Related Works

In WSNs, two principal obstacles for enhancing the service that are the communication efficiency and the energy consumption. Indeed, the energy consumption and link quality is strongly linked to the traffic load. Thus, the best technique to deal with communication efficiency and energy consumption consist to distribute in a fair and efficient manner the traffic across the network. As result,

Manuscript received May 5, 2019; revised November 7, 2019.
doi:10.12720/jcm.14.12.1224-1228

energy-efficiency is a challenge in WSNs because the capacity of sensor nodes' batteries is limited [3].

We first start with some works that offer a thorough study of multipath routing techniques [4], [5]. These works describe and explain the important role of multipath routing in WSNs and demonstrate its effectiveness, despite the presence of resource constraints such as limited energy, storage, and computational capacity. Furthermore, these studies summarize the problems encountered during the implementation of multi path routing algorithms [6].

The authors in [4] present a taxonomy of existing multipath routing algorithms into three categories: the disjoint path, the braided path and the N-to-1 multipath discovery. In this work, the disjoint multi path routing has been studied. In this category, a number of multiple paths to the destination are provided but two conditions are required. The first one is that the node must participate in two paths disjoints; second, node must participate once in the same path. The DSR, AODV and MCP-DE (Multi Constraint Path-Delay ETX) algorithms has been compared. The results of simulation has showed that the AODV realized best performance in situations of low mobility and high-density network.

In [5], the authors analyzed three categories mainly based on the special techniques used in building multiple paths: infrastructure based, non-infrastructure based and coding based. For each category, the authors present and analyze the protocols. Moreover, the design goals, challenges and evaluation metrics for multipath routing protocols are summarized.

Next, the objective of energy-efficient routing is save energy extending the network lifetime. Because the energy affect directly the principal tasks of sensor, it is necessary to manage the energy efficiently for ensuring the function of network as long as possible. To this end, several research works focus on the efficient energy routing [7], [8].

Finally, load balancing is a real issue in WSN for enhancing its performances. Thus, the authors in [9] consider that the load balancing does not means that all node has the same load of traffic, but search rather the suitable strategy according to the network state that improve the node lifetime and consequently the network life time. In this work, this problem is considered by proposing a comparative study of some techniques used in wireless sensor networks for load balancing; in particular, the cluster based, the algorithm based and the protocol based.

## III. Problem Statment

We modelled the network by an undirected graph $G = (N, L)$ where the $N$ vertices are the sensor nodes of the network. The set of edges $L$ represents the wireless links between the pair source-destination nodes. We consider two sensors as neighbors if the Euclidean distance separating them is less than or equal to the communication range $Rc$. Therefore, this is defined as the area in which another node can be located to receive data [3]. The sensing range $Rs$ presents the range within which nodes are able to sense the signal. Thus, the set of possible communications is defined as follows:

$$c = \{(s_i, s_j) \in n^2 \mid s_j \text{ receives the message of } s_i\} \quad (1)$$

and thereby, the neighborhood of node $s_i$ is:

$$Neig(s_i) = \{s_j \in N \mid (s_i, s_j) \in L \quad (2)$$

Typically the total flow on an edge $(i, j)$ is limited by its capacity $u_{ij}$:

$$f_{ij} = \sum_c x_{ij}^c \leq u_{ij} \quad (3)$$

where, $x_{ij}^c$ means the set of flows over the edges $(i, j) \in L$.

In addition, we assume the following points:

- All sensors in the network are homogeneous in terms of physical characteristics.
- The base station is stationary.
- All sensors in the network are time-synchronized.
- Each sensor has a unique identifier id.
- Initially, each sensor has the same amount of energy, but its energy consumption is different over time.
- Batteries cannot be replaced after sensor deployment.

## IV. Proposed Routing Algorithm

### A. Principal

Our contribution consists in proposing a multi-path routing algorithm taking into account several criteria among them the link quality to improve LBR algorithm. Thus, Quality LBR algorithm (QLBR) is an extension of the Load Balancing Routing (LBR) algorithm, which is in turn an improvement of the AODV. Concerning the AODV routing protocol that uses only the number of hop as the optimal criterion for evaluating the path and in the LBR algorithm [10], the quality of link is not taken into account. Otherwise, the QLBR algorithm integrate a multi-metric strategy for mobile sensor networks (as shown in Fig. 1). Nodes are often mobile and have limited energy capacity. In this section, we will interpret the multi-metric routing model using energy mobility, traffic load and link quality as criteria. We explain how to combine them to make the best dynamic routing decisions.

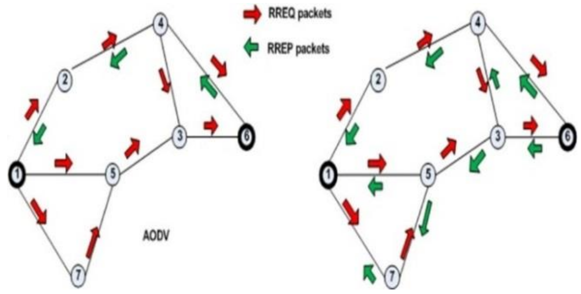


Fig. 1. Mechanism of the QLBR vs. AODV.

*1) Energy*

Energy consumption is a major problem in WSN networks; both packet transmission and reception are a costly process in term of energy. The choice of the path in QLBR algorithm based on the residual energy of the sensors that route the information between the source and the destination. Thus, the router selection depends on the level of residual energy. The energy factor of a sensor node $E$ is calculated by the following equation:

$$E = \frac{E_r}{E_{max}} \tag{1}$$

where: $\boldsymbol{E_r}$ stands the remaining energy of the node and $\boldsymbol{E_{max}}$ the maximum energy. The factor $\boldsymbol{E}$ varies from 0 (dead node) to 1 (full power). Once the energy level of the sensors decrease, this factor becomes a dominant criterion in routing decisions.

*2) Mobility*

Mobility has become a necessity in sensor networks as they are often used in mobile environments. Mobility helps network connectivity, provides healing of topological fault and widens the application field of WSN, although it influences path stability. Therefore, to ensure an effective algorithm, mobility must be taken into account to avoid frequent route establishment. For this, the speed of the mobile node is used as a measure of mobility. Thus, the speed $S$ is calculated by the following equation:

$$\boldsymbol{S} = \frac{\boldsymbol{S_l}}{\boldsymbol{S_{max}}} \tag{2}$$

Where: $\boldsymbol{S_l}$ is limit speed and it is calculated as follows:

$$S_l = S_{max} - S_{node}$$

$\boldsymbol{S_{max}}$ presents the maximum speed allowed by our algorithm, $\boldsymbol{S_{node}}$ is the node speed. $\boldsymbol{S}$ varies between 0 and 1, so that 0 corresponds to the fastest node and 1 to the slowest one. The node with the lowest mobility is considered an ideal candidate for the next hop. This can significantly increase the network lifetime.

*3) Traffic load*

In WSN, network saturation and traffic congestion problems are more frequent. In addition, as the energy of mobile nodes is limited, load balancing becomes a recurring task in this type of network. To avoid over or under load of the sensors, it is wise to establish a uniform load at each sensor. This helps to use efficiently the resources of network, reduce packets loss and increase the delivery ratio. The sensor uses a buffer to store received packets in a limited capacity queue$\boldsymbol{Q_{max}}$. If the queue $\boldsymbol{Q_{length}}$ is full, all future packets will be rejected until a slot is released. We define the length of the free space in the queue as the empty space $\boldsymbol{Q_s}$ calculated as follows:

$$Q_s = Q_{max} - Q_{length}$$

The traffic load $TL$ is calculated using equation (3), $TL$ varies between zero and one, so the higher $TL$ value implies more available space in the queue.

$$TL = \frac{Q_s}{Q_{max}} \tag{3}$$

*4) Link quality*

The low quality of link leads to packet loss and communication failure. Noted that, the shortest paths have not necessarily have good link quality. Therefore, the quality of the link is an important factor in choosing the path. As indicated in [3] signal strength is used as link quality $\boldsymbol{LQ}$ indicator.

$$LQ = \frac{SS}{SS_{max}} \tag{4}$$

where: $SS$ indicates the signal strength of the received packets and $\boldsymbol{SS_{max}}$ indicates the maximum signal strength. In this case, link quality $LQ$ varies in [0, 1] interval. Thus, the value 1 indicates the strongest signal of a received packet.

### *B. QLBR Algorithm Description*

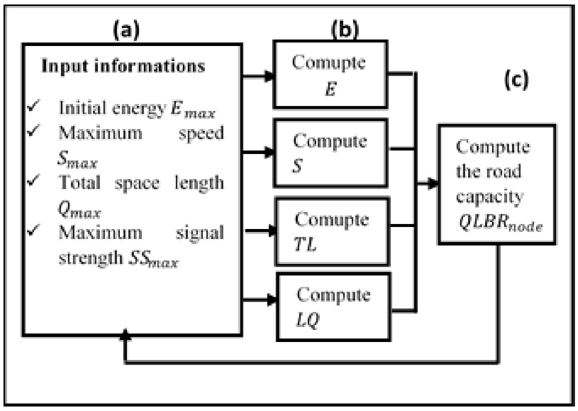


Fig. 2.Synopsis process of QLBR.

The QLBR algorithm is essentially based on combination of multiple criteria to improve the network performance. We introduce the energy, traffic load, speed and the signal strength as the decisive criteria for choosing the best path as shown in Fig. 2. As indicated in [11], multi-metric algorithms often use the weighted sum approach to combine multiple metrics on an available path. For this, the following equation is used for the previously mentioned metrics:

$$\boldsymbol{QLBR_{node} = \alpha.M + \beta.E + \gamma.TL + \delta.LQ} \tag{5}$$

where: α, β, γ and δ are coefficients for mobility, traffic load, residual energy and link quality criteria respectively. These weights can be selected according to the network application. For maintaining the normalization in the range [0.1], the sum of weights must be equal to 1 (α+ β+γ + δ = 1).

After a series of simulations and analysis of the obtained results, it was observed that the optimum weight distribution was as follows: α= 0.4, β= 0.2, γ= 0.2 δ=0.2.

In this part, we detail the functioning of the QLBR algorithm for the exchange of data between source and destination nodes.

*1) Routes discovery*

Like all reactive protocols, in QLBR, the source node uses the route discovery mechanism before data is exchanged with the destination. Thus, the source node broadcasts a route request packet (RREQ) comprising an additional field containing the capacity of the route. The node ignores the RREQ already received. Otherwise, it maintains the reverse path to the source. Therefore, the last hop will be the next hop in its routing table.

Then, the node calculates its $QLBR_{node}$ value (eq. 5), and it updates the $QLBR$ field with the average of its $QLBR_{node}$ value and the transmitter one (eq. 6).

$$QLBR = \frac{QLBR_{node} + QLBR}{2} \tag{6}$$

The node rebroadcasts the updated RREQ packet to its neighbors, so that the packet propagate as much as possible in the network. Broadcast stops when the destination node is reached.

*2) Routes establishing*

Like the behaviour of AODV is based on the minimum number of hops for route selection, the destination node responds to the received RREQ request first and ignores packets that will arrive later. However, our algorithm defines a delay time $D_t$, the destination node expects ($D_t$) the arrival of several RREQ. When a packet arrives, if the old QLBR ($\boldsymbol{QLBR_{des}}$) is greater than the new receive, the destination ignores this packet, otherwise it updates the old value $\boldsymbol{QLBR_{des}}$ in its routing table. So that, the destination responds to the source by choosing the path with $\boldsymbol{QLBR_{des}}$ maximum value. Although the number of hops is also an important factor in the routing decision; $\boldsymbol{QLBR_{des}}$ is the ratio between the QLBR value of a path to the number of hops $\boldsymbol{h_{cpt}}$ that are traversed. $\boldsymbol{QLBR_{des}}$ is calculated by the following equation:

$$QLBR_{des} = \frac{QLBR}{h_{cpt}} \tag{7}$$

## V. Simulation

In this section, we evaluate the performance of our proposed QLBR algorithm, comparing its performances with that of other routing algorithms: the original version of AODV and LBR. For this, we choose some performance metrics such as consumed energy, alive nodes and dead nodes.

The parameters used in our experiments are summarized in the table below:

TABLE I: SIMULATION PARAMETERS

| Parameters | Value |
|---|---|
| Routing protocols | AODV, LBR, QLBR |
| Simulator | Ns-2.35 |
| Mobility model | Rondom way point |
| Area. | 600m*600m |
| Simulation time | 900s |
| Number of sensors | 100 |
| Initial energy. | 15J |
| Size of packet. | 100 octets |
| Sensor speed | 1 to10 m/s |
| Traffic | CBR |
| MAC. | IEEE 802.11 |
| Radio propagation model. | Two-ray ground reflection |

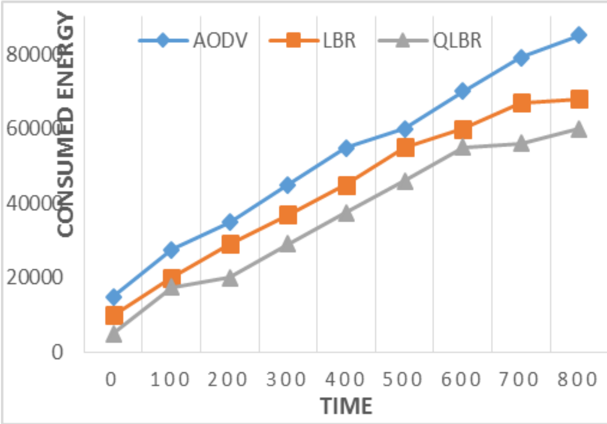


Fig. 3. Consumed energy vs. Time.

Fig. 3 show the amount of consumed energy over time. We note that our algorithm QLBR reduce considerably the average energy consumption compared to LBR and AODV, while decrease consumed energy by 11% vs. LBR and 30% vs. AODV. This can be justified by the fact that we opted to include the link quality in the route discovery phase. In other words, the quality of the link is used in the choice of route by reducing the route establishment (at the same time reducing transmissions between sensor nodes) significantly improves energy consumption.

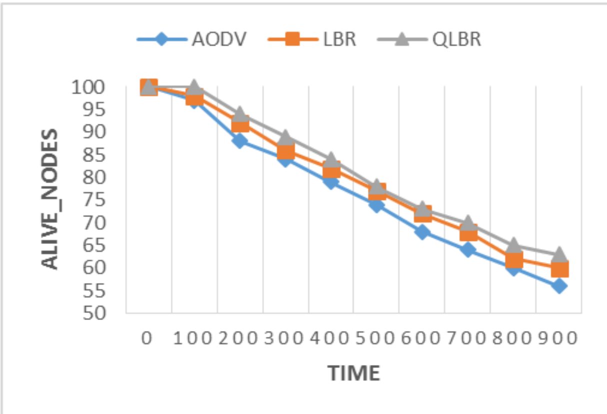


Fig. 4. Live nodes vs. Time

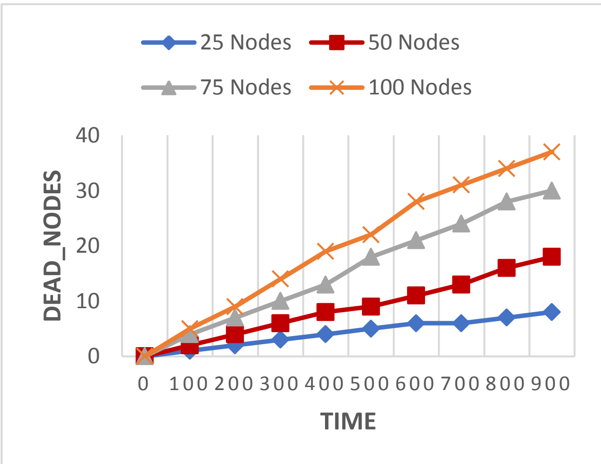


Fig. 5. Dead nodes vs. total number of nodes.

Fig. 4 and Fig. 5 illustrate the dead and alive sensor nodes over time. We can see the improvement introduced by our QLBR algorithm in terms of number of live nodes. These last are increased by 9 % compared to LBR and 15% to AODV. This is can be explained by the energy savings achieved on each node. As a result, the lifetime of the full network can be extended.

## VI. Conclusions

In the light of this paper, we have proposed a multi path routing algorithm based energy-efficient to improve the network lifetime. This algorithm respects the capacity of the sensors for routing data. This by combining several sensor qualities to find the best candidate in the research for the path. In our study, the critical criteria that taken into account are residual energy, node mobility, traffic load and link quality. With regard to the residual energy, the sensor can be involved for a long time in the data routing in the route without need to change it. As a result, less overhead for finding the path. Mobility ensures that the fast sensor does not participate in the routing of data for fear of moving away from neighbors. In addition, the high traffic load sensor is not suitable for routing data. The quality of the link is very important criteria for avoiding the breaking of the roads during routing. Thus, the proposed QLBR algorithm improves the stability of the road and then maximizing the delivery of packets. The simulation results confirm that the QLBR algorithm achieves an energy gain of 11% compared to the LBR algorithm and extended network lifetime by about 9%.

Future works will targeted the efficiency of our algorithm in terms of communication efficiency like as Packet Delivery Ratio (PDR), Normalized Routing Load (NRZ), packet loss and throughput.

## References


[1] T. Rault, A. Bouabdallah, and Y. Challal, "Energy efficiency in wireless sensor networks: A top-down survey," *Computer Networks*, vol. 67, pp. 104–122, 2014.

[2] H. Farooq and L. T. Jung. "Energy, traffic load, and link quality aware ad hoc routing protocol for wireless sensor network based smart metering infrastructure," International *Journal of Distributed Sensor Networks*, 2013.

[3] R. Kacimi, R. Dhaou, and A. L. Beylot, "Load balancing techniques for lifetime maximizing in wireless sensor networks," *Ad Hoc Networks*, vol. 11, pp. 2172-2186, 2013.

[4] P. Y amunadevi, T. Vairam, C. Kalaiarasan, and G. Yidya. "Efficient comparison of multipath routing protocols in WSN," in *Proc. International Conference on Computing, Electronics and Electrical Technologies (ICCEET)*, 2012.

[5] K. Sha, J. Gehlot, and R. Greve, "Multipath routing techniques in wireless sensor networks: A survey," *Wireless Com*., vol. 70, pp. 807-829, 2012.

[6] H. Y. Kim, "An energy-efficient load balancing scheme to extend lifetime in wireless sensor networks," *Cluster Computing*, vol. 19, pp. 279-283, 2016.

[7] E. J. Duarte-Melo and M. Liu, "Analysis of energy consumption and lifetime of heterogeneous wireless sensor networks," *Globecom*, 2002.

[8] A. Ahad1, Z. Ullah1, B. Amin, and A. Ahmad. "Comparison of energy efficient routing protocols in wireless sensor network," *American Journal of Networks and Communications*, vol. 6, pp. 67-73, 2017.

[9] S. Shivapur, S. G. Kanakaraddi, and A. K. Chikaraddi, "Load balancing techniques in wireless sensor networks: a comparative study," *International Journal of Emerging Technology in Computer Science & Electronics*, vol. 14, 2015.

[10] S. Khalid, A. Masood, F. B. Hussain, H. Abbas and A. Ghafoor, "Load balanced routing for lifetime maximization in mobile wireless sensor networks", *International Journal of Distributed Sensor Networks*, 2014.

[11] M. Javadi, H. Mostafaei, M. U. Chowdhurry, and J. H. Abawajy, "Learning automaton based topology control protocol for extending wireless sensor networks," *Lifetime Journal of Network and Computer Applications*, August 2018.


**Fatiha Djemili Tolba** was born in Annaba Province, Algeria, in 1978. She received the engineer degree from the University of Badji Mokhtar Annaba of Algeria, in 2002 and the Ph.D. degree in computer science from the University of Franche Comté of Beçanson (UFC), France, in 2007. His research interests include wireless sensor networks, MANET routing protocols and network Security.

**Pascal Lorenz** received his M.Sc. (1990) and Ph.D. (1994) from the University of Nancy, France. Between 1990 and 1995 he was a research engineer at WorldFIP Europe and at Alcatel-Alsthom. He is a professor at the University of Haute-Alsace, France, since 1995. His research interests include QoS, wireless networks and high-speed networks. He is the author/co-author of 3 books, 3 patents and 200 international publications in refereed journals and conferences.