Multi-path routing algorithm for Wireless sensor networks

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Abstract—**Sensor nodes forming wireless sensor networks (WSNs), are generally equipped with a low computing capacity, a small antenna and a very limited energy source; which makes the batteries critical resources from where their use must be efficient. On the other hand, The used communication protocol to deliver data from source to destination in a WSN is the biggest energy consumer. Indeed, in a dense WSN, each node may route messages to a destination node either through short-hops or long-hops, by using long or short radio range. Thus, the hop lengths optimization can save energy. In this paper, we propose an multi-path routing algorithm based on the ideal hop's range to improve WSN power consumption. The simulation results obtained by applying the proposed algorithm on several WSNs reveal a high performance regarding WSNs energy consumption and networks lifetime.**

Index Terms—**Wireless sensor networks,hops lengths, Multi-paths routing algorithm, energy efficiency, network lifetime.**

I. INTRODUCTION

Wireless sensor Networks (WSNs) are listed by Business 2.0 as one of the six technologies that will change our world [1], also Technology Review at MIT and Global future identify WSNs as one of the 10 emerging technologies that will change human's life [2]. Indeed, In the last years, Wireless sensor networks have been used in many applications like military, surveillance, biomedical health monitoring, home applications, disaster management, forest fire detection, seismic detection, habitat monitoring, inventory tracking, animal tracking, hazardous environment sensing and smart spaces, general engineering and commercial applications [3]–[7]. In the most cases, it's impossible to replace or recharge the batteries of nodes given the nature of the monitoring areas [1], [8]; therefore each node should have strict limitations in the usage of its energy source. Thereby, the nodes batteries in

a WSN are considered as scarce resources and should be used efficiently [9].

In a typical WSN, which may contain up to 1 million nodes [10], a sensor node consumes energy from its battery in sensing, processing, sending and receiving data. Several studies showed that the most energy-consuming task is sending/receiving data which uses the radio module that provide wireless communications [1], [2], [8]; indeed, the energy consumed, by a node, when transmitting 1 bit of data by its antenna on the wireless channel is equivalent to the energy required to execute thousands of instructions by its CPU [11]. Therefore, the communication protocol used in a WSN affects largely the energy consumption and the network's lifetime [12], [13].

In WSNs, sensors don't have the necessary power and the sufficient communication range to communicate data directly to the base station. So, the multi-hops architecture is used to forward data from the source to the destination node [8], [14]. Hence, in WSNs, a sensor don't senses and sends only its own data but also have to act as a router i.e., to forward data of its neighbors.

In a dense WSN, a multi-hops protocol is used to transmit data from a source to a destination. In nowadays, all modern sensors are equipped with developed radio transceivers, which have the capacity to adjust their transmitting powers [15], [16], in order to avoid using a large radio range to contact a nearby node, so some distant destinations can be reached with either a big number of short-hops or a few number of long-hops. Fig. 1 depicts these two strategies.

The problem over the required number of hops, to save energy, comes from the reality that each strategy (long-hops Vs short-hops) has its own advantages and its own disadvantages. Transmitting data over many short-hops (this path is depicted
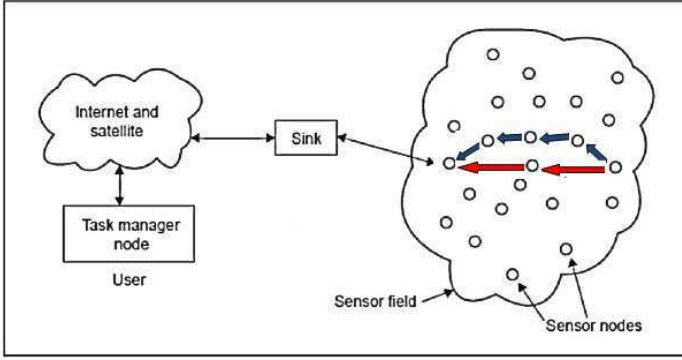
Fig. 1. Routing over short-hops and long-hops.

with blue arrows in Figure 1) helps to reduce energy consumed by transmissions which is proportional to the communication distances but increases the energy consumed by reception, since the energy consumed when receiving data can't be neglected [6]. However, transmitting data over long distances [5], by using long-hops (this path is depicted with red arrows in Figure 1), reduces the reception costs, as the number of nodes involved in data routing decreases, but increases the energy consumed by transmissions, since the distances of communications are long.

Nowadays, multi-path routing approaches are widely used in wireless sensor networks to improve network performance through efficient utilization of available network resources [18], [20]. Indeed, single-path routing algorithms, also called classical routing algorithms, maintain the same path during the communication between a source and a destination, which make the nodes consume more energy, unlike the multi-path algorithm which update the path periodically to assure a best load balancing between nodes. In this paper, we will present a multi-path routing algorithm (MPA) based on the optimal hop rage [19]. Proposed algorithm is then compared to a single-path routing algorithm (Short path algorithm) based on *Dijkstra* algorithm to find the shortest path between the source node and the destination node.

II. OVERVIEW ON ROUTING IN WSNs

The limited characteristic of the nodes forming wireless sensor networks, make the routing task in these multi-hops networks much more challenging compared to the traditional ad-hoc networks [21], [22]. In the case when some nodes die out during network activity due to energy depletion of the sensor nodes, this issue should not makes the network out of services. Moreover, since the applications of WSNs are application specific, routing protocols should be able to satisfy the QoS demands.

According to the differences between wireless sensor networks and ad-hoc networks, numerous routing protocols were developed to address the routing challenges imposed by the limitations of sensor networks.

Al-Karaki et al. [21] classified the existing routing protocols in two different categories:

1) Network structure
2) Protocol operation

In the first class, routing algorithms are classified as flat, hierarchical and location-based routing protocols. Flat routing protocols are designed for networks with homogenous nodes. This category includes Directed Diffusion, Sensor Protocols for Information via Negotiation (SPIN), Rumor Routing, Minimum Cost Forwarding Algorithm (MCFA), and Energy-Aware Routing (EAR). Hierarchical routing protocols were originally proposed to improve network scalability and energy efficiency through node clustering. In this group of routing protocols, all the sensor nodes are grouped into clusters and one node with more resources in each cluster is assigned as the cluster head. Several routing protocols such as Threshold-Sensitive Energy-Efficient Sensor Network Protocol (TEEN), Adaptive Periodic Threshold-Sensitive Energy-Efficient Sensor Network Protocol (APTEEN), Low-Energy Adaptive Clustering Hierarchy (LEACH), Power-Efficient Gathering in Sensor Information Systems (PEGASIS) and Two Tire Data Dissemination (TTDD) fall in this category. Routing protocols in the second group utilize the exact location of the sensor nodes to make routing decisions. The geographic locations of sensor nodes can be obtained directly using Global Positioning System (GPS) devices or indirectly by exchanging some information regarding to the signal strengths received at each node. However, since localization support requires specific hardware components and imposes significant computational overhead to the sensor nodes, this approach cannot be easily used in resource-constrained wireless sensor networks. Geographic and Energy-Aware Routing (GEAR) and Geographic Adaptive Fidelity (GAF) can be referred as the geographic routing protocols [20], [23].

Concerning the protocol operation, all existing routing protocols can be categorized into negotiation-based, query-based, QoS-based, multi-path-based and coherent-based protocols. The main idea in the design of negotiation-based routing protocols is to provide energy-efficient communication by reducing data redundancy during data transmission, we note as an exemple for this category the SPIN family of protocols. In the query-based routing protocols, a sink node diffuse a query message throughout the network to obtain the desired sensing task. all nodes sensed any related information, reply with the collected data to the sink node through the reverse path, we quote as an example Directed Diffusion and Rumor Routing. The QoS-based routing protocols is designed to satisfy QoS demands of different applications. The key aim of these class of protocols is to establish a trade-off between energy consumption and data quality. Sequence Assignment Routing (SAR) protocol, SPEED , Multi-path Multi-SPEED(MMSPEED), Energy-aware QoS Routing Protocol and Delay-minimum Energy-aware Routing Protocol(DERP) can be considered as the QoS-aware routing protocols. in contrary with single-path routing algorithms, multi-paths routing protocols allow each source node to find multiple paths towards the sink node to improve network performance. There

are several protocols in this category such as Braided Multi-path Routing and N-to-1 Multi-path Routing Protocol. In coherent data processing-based routing protocols group, data are sent to the sink in order to reduce data redundancy. Therefore, energy efficiency is highly considered by these routing protocols. Routing protocols such as Directed Diffusion , SPIN and SAR utilize data aggregation and can be categorized as the coherent data processing-based routing protocols [23], [24].

From now, our interests are focused on the multi-paths routing approach and the related issues that should be considered in the design of these protocols for wireless sensor networks.

III. MULTI-PATH ROUTING FOR WSNs

Multi-path routing scheme is used as one of the best solution to overcome the power consumption and the limitation of single-path routing approach. In this section, we will discuss the multi-path routing approach and he main design issues in the development of this type of routing protocols.

The routing inside wireless sensor networks uses multi-hop routing scheme via message forwarding is more efficient than single-hop routing; in a high dense network. even so single-path routing assure rapid routing and data transfer because each node uses only one path before sending the collected data. However, a single path can become ineffective by a defect in a sensor node during packet forwarding. thereby, the multi-path routing scheme provides improved transmission reliability, fault tolerance, congestion control, and quality of service. The multi-path routing scheme establishes multiple paths between the source and the destination. The multi-path routing reduces the load on a sensor node and extends the lifetime of sensor networks [24].

In multi-path routing, multiple paths are utilized for data routing. Therefore not only the shortest path but also relatively long distance paths are also available for data routing. In the proposed multi-path routing algorithm, we used the interval that assures the optimal energy consumption, which used this condition to select the next node to construct the routing path [19]. Figure 2 depicts a wireless sensor network which is using a Multi-path routing scheme.
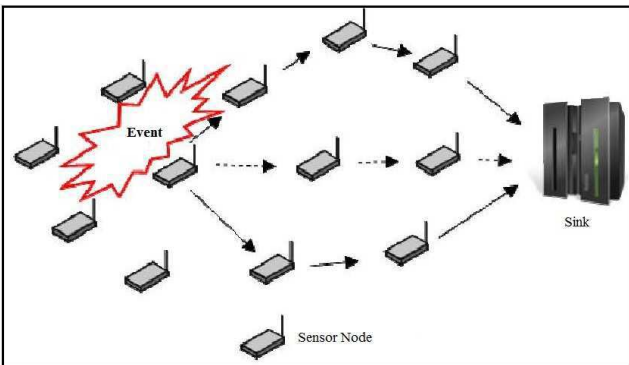

Fig. 2. Multi-path routing.

IV. THE PROPOSED ALGORITHM

In this section, the Multi-path Algorithm (MPA) is used to find multiple optimal routes, between the emitter and the sink which guarantees the minimum energy consumption. Before proceeding, these assumptions are made about the network:

1) The network is highly dense
2) Each node in the network has a distinct ID.
3) All the nodes deployed are energy/power constrained, homogeneous and stationary.
4) The antennas sensitivity threshold of nodes is given.
5) The antennas nodes can detect the power of the received signal (Signal force).

In the proposed algorithm, there are three types of messages, Init_REQ(NodeID), ACK(nodeID, ParentID) and DataMessage(ParentID,ChildID,Data). A node broadcast an Init_REQ (nodeID) to its neighbors using the ideal hop range to inform them by its ID, each node interested by the Init_REQ (the nodes which are situated at a distance accepted by the condition presented and hear the Init_REQ), will add the senderID to the list of its parents (multiple parents means multiple paths) and reply with an ACK to inform the sender by its ID. The sender, when it receives an ACK from a node, adds the nodeID to the list of its children, to construct multiple routes. In the proposed algorithm, the sink is the first node which sends an Init_REQ, it means the algorithm is started by the sink, and ends when all the nodes have parents. The nodes in the network use hops which satisfy the condition presented in the previous section (hop range).

The pseudo code of the initialization phase is showed in Algorithm 1. Nodes which are in the topology have two roles: parent and child, except the sink which has only children and the end nodes which have only parents.

Algorithm 1 initialization Phase

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repeat

   $Node_i$ broadcast an Init_REQ($nodeID_i$) using the HopRange;

   for Each $node_j$ hears the Init_REQ and SignalForce(Init_REQ)$\approx$SensibilityThreshold$_{Node_j}$ **do**

      Add $node_i$ to the list of parents;

      Send ACK($nodeID_j$,$nodeID_i$)

   end for

   for Each $node_k$ hears an ACK and NodeID$_k$=ACK.ParentID **do**

      Add ACK.NodeID to the list of children;

   end for

until all nodes have at least a parent.

After the initialization phase ends, each node knows its children and its parents (excepting the sink and the ends nodes). When a node in the network has data to share with the Sink it chooses the first parent in the list of its parents and sends the DataMessage (NodeID, ParentID, Data). In his turn, the parent node receiving the DataMessage forward it directly to its first parent in its list of parents and so on, this task is repeated until the data arrives at the sink.

In order to preserve nodes batteries and to ensure a uniform consumption of energy between all the nodes of the network, when a node has data to send to the sink for a second time it chooses the second parent (second path) in its list of parents, and each time when it has data to send it chooses the next parent or the next path. This so as not to solicit only the first parent and ensure a uniform distribution of energy consumption between its different parent and usually between the different nodes of the network, which we call multi-path routing.

The pseudo code of sending a message is showed in Algorithm 2.

Algorithm 2 Send Message

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while a node has data to send **do**
    ParentID=The ID of the first Parent from PartentList;
    Move the selected parent to the Queu of the PartentList;
    Send DataMessage(nodeID, ParentID,Data)
end while

V. SIMULATIONS AND RESULTS VALIDATION

In order to validate the proposed algorithm and measure its performances, we compared it to the shortest path algorithm (SPA) [25] which uses the *Dijkstra* algorithm to build the shortest routing path. The comparison was based on the energy dissipation and the lifetime of the network. Algorithms have been simulated for several numbers of nodes (100, 200, 300, 400, 500 and 800) by considering set of parameters shown in table I.

All network nodes were randomly scattered in 1000×1000 meters, randomly generated topologies were used. The sink was fixed at the origin (0,0) and the initial energy nodes were assigned to $5j$.

TABLE I
EXPERIMENTAL STUDY PARAMETERS

Parameters	Values
Number of nodes	100-500 and 800 nodes.
Sink position	(0,0)
Initial energy	5j
Transmission rage	85 meters
Environment	The free space path loss exponent
Power consumption in transmission	15 mA
Power consumption in receiving	10 mA

Figure 3 illustrates the energy consumption in deployed networks (100, 200, 300, 400, 500 and 800 nodes), using the proposed algorithm (MPA) and the shortest path algorithm (SPA). According to the figure 3, when the density of the nodes was low (100 nodes), the energy consumed was almost equivalent, once the density increased the difference between the energy consumed by the MPA and that of SPA also increased, this is due to the fact that the proposed algorithm limits the energy consumption during receptions by involving just a small number of nodes when applying multi-hop routing

strategy, unlike the SPA which involve a large number of nodes when building a routing path using single-hop strategy especially in very dense network.
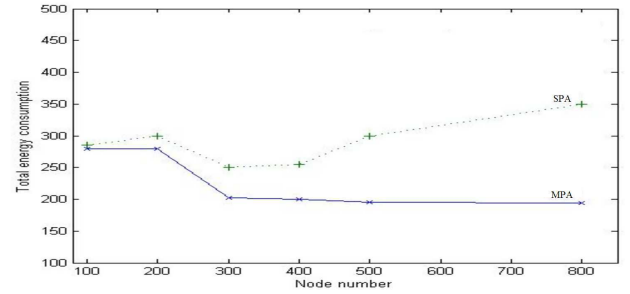

Fig. 3. Energy consumption : MPA Vs SPA

As shown in Figure 4, the MPA ensures a very high network lifetime. this is due to the fact that the MPA use the optimal routing path involving a small number of intermediate nodes thus conserving energy. On the other hand the SPA routing path building strategy involve a high number of intermediate nodes especially in very dense network. The massive participation of nodes in the routing path implies a high energy consumption which causes a loss of network lifetime.
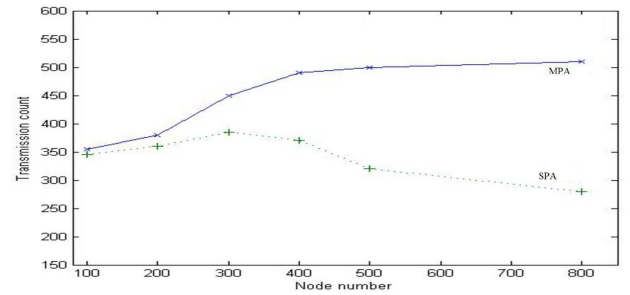

Fig. 4. Network lifetime : MPA Vs SPA

VI. CONCLUSION

The sensing technology and in particular wireless sensor networks are used in several applications, due to their multiples advantages. However, this type of network has many challenges to raise. The biggest one is the energy consumption. To remedy to this problem several techniques have been proposed and developed, among which the multi-hops routing strategy.

In this article, we have proposed a multi-path routing algorithm (MPA), which uses the optimal length hops to establish multiples optimal paths between a source node and a destination node. The efficiency of the proposed algorithm is validated by simulations. The simulation results show that MPA overcome the SPA algorithm, by limiting the energy consumption and by extending the networks lifetime.

REFERENCES

[1] M. Ilyas, and I. Mahgoub. "Handbook of sensor networks: compact wireless and wired sensing systems," CRC press. (2004).

[2] M. Kheireddine, R. Abdellatif, and G. Ferrari. "Genetic Centralized Dynamic Clustering in Wireless Sensor Networks," international Journal of Computer Network and Information Security. Vol 7(8), pp. 1. (2015).

[3] G. Simon, M. Maroti, A. Ldeczi, G. Balogh, B. Kusy, A. Nadas, and K. Frampton, "Sensor network-based countersniper system," in Proceedings of the 2nd international conference on Embedded networked sensor systems, pp. 1-12. ACM. (November 2004).

[4] M. Castillo-Effer, D. H. Quintela, W. Moreno, R. Jordan, and W. Westhoff. "Wireless sensor networks for flash-flood alerting. In Devices, Circuits and Systems," in proceedings of the Fifth IEEE International Caracas Conference on. Vol. 1, pp. 142-146. IEEE. (November 2004).

[5] Y. Li, and Y. Liang. "Compressed Sensing in Multi-Hop Large-Scale Wireless Sensor Networks Based on Routing Topology Tomography," arXiv preprint arXiv:1709.00604. (2017).

[6] K. Lorincz, D. J. Malan, T. R. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, and S. Moulton. "Sensor networks for emergency response: challenges and opportunities," IEEE pervasive Computing. Vol 3(4), pp. 16-23, (2004).

[7] H. Wu, X. Chen, C. Shi, Y. Xiao, and M. Xu. "An ACOA-AFSA fusion routing algorithm for underwater wireless sensor network," international Journal of Distributed Sensor Networks, Vol. 8(5), pp. 920505. (2012).

[8] I. F. Akyildiz, and M. C. Vuran. "Wireless sensor networks," vol. 4. John Wiley & Sons. (2010).

[9] A. Chakraborty, S. K. Mitra, and M. K. Naskar. " A genetic algorithm inspired routing protocol for wireless sensor networks," international Journal of Computational Intelligence Theory and Practice, Vol. 6(1), pp1-8. (2011).

[10] J. Xue, T. Zhang, Y. Yan, W. Wang, and S. Li. "Cooperation-based Ant Colony Algorithm in WSN," JNW, Vol. 8(4), pp. 939-946. (2013).

[11] J. Yick, B. Mukherjee, and D. Ghosal. "Wireless sensor network survey. Computer networks," vol. 52(12), pp. 2292-2330. (2008).

[12] S. Rachamalla, and A. S. Kancharla. "Power-Control Delay-aware routing and MAC protocol for Wireless Sensor Networks," in 12th International Conference Networking, Sensing and Control (ICNSC), IEEE. pp. 527-532. IEEE. April (2015).

[13] S. Singh, and R. M. Sharma. "Optimization Techniques in Wireless Sensor Networks," in Proceedings of the Second International Conference on Information and Communication Technology for Competitive Strategies. pp. 140. ACM. (March 2016).

[14] A. Hadir, K. Zine-Dine, M. Bakhouya, J. El Kafi, and D. El Ouadghiri. "Performance Evaluation of DV-Hop Localization Algorithm for Geographical Routing in Wireless Sensor Networks," Procedia Computer Science, Vol. 113, pp. 261-266. (2017).

[15] A. L. Kakhandki, and S. Hublikar, "Energy efficient selective hop selection optimization to maximize lifetime of wireless sensor network," alexandria Engineering Journal. (2017).

[16] U. M. Pesovic, J. J. Mohorko, , K. Benkic, and Z. F. Cucej. "Single-hop vs. Multi-hop-Energy efficiency analysis in wireless sensor networks," in 18th Telecommunications Forum, TELFOR. (2010).

[17] G. Meijer, K. Makinwa, and M. Pertijs, 2nd ed. Smart sensor systems: Emerging technologies and applications," John Wiley & Sons, 2014.

[18] Y. Chen, X. Lv, S. Lu, and T. Ren."A Lifetime Optimization Algorithm Limited by Data Transmission Delay and Hops for Mobile Sink-Based Wireless Sensor Networks" journal of Sensors, (2017).

[19] K. Mekkaoui, A. Rahmoun. "Optimal path routing algorithm for wireless sensor networks," in Proceedings of the first international conference on artificial intelligence and its applications (AIAP2018), pp. 179-186 .El-Oued, Algeria, 4-5 December 2018.

[20] R. Marjan and all,"Multipath routing in wireless sensor networks: survey and research challenges ," Sensors, vol. 12, N. 1, pp. 650-685, 2012.

[21] J.N. Al-Karaki, A.E. Kamal, "Routing Techniques in Wireless Sensor Networks: A Survey," IEEE Wirel. Commun. 2004, 11, 628.

[22] K. Akkaya, M. Younis, "A Survey on Routing Protocols for Wireless Sensor Networks," international journal of Ad-Hoc Networks, vol. 3, pp. 325349. 2005.

[23] G. Priya, "Multipath routing in wireless sensor networks: a survey and analysis," IOSR Journal of Computer Engineering, vol. 16, n. 4, pp.27-34, 2014.

[24] M. Z. Hasan et al, "A survey on multipath routing protocols for QoS assurances in real-time wireless multimedia sensor networks," IEEE Communications Surveys & Tutorials, vol. 19, n. 3, pp.1424–1456 , 2017.

[25] M. Shan et al, "Building maximum lifetime shortest path data aggregation trees in wireless sensor networks," ACM Transactions on Sensor Networks (TOSN), vol. 11, n. 1, pp. 11, 2014.