Enhancing Connectivity and Energy Efficiency in Mobile Wireless Sensor Networks with SHEM

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***Abstract*—The wireless sensor network can be useful in many domains such as military field, environmental control, medicine and healthcare. We, specially, focus on networks with mobiles nodes. Such networks require continuous dynamic reconfiguration to maintain effective communication between the nodes. Maintaining communication links and connectivity is one of the most important challenges used in wireless sensor networks to reduce energy consumption especially in a mobility situation. The nodes of the sensors communicate with each other using different types of topology such as mesh, tree, chain, and so on. Therefore, it is important to form an effective topology that ensures neighboring nodes a minimum distance, reduces the lost message between sensors, reduces interference, thus reducing the waiting time for sensors to transmit data. Depending on their roles in the Wireless Sensor Networks (WSN), nodes can move individually or in groups with respect to a reference system, which changes the topology of the network. Topology changes occur in a dynamic WSN when nodes disconnect or connect and when we also add or remove nodes. In this paper, we proposed a topology control, connectivity maintenance, energy consumption reduction, mobility system, called SHEM. SHEM relies on individual and collective movements after the network setup by the Sensor Hybrid Energy (SHE) algorithm. We explored the impact of mobility on the performance of the wireless sensor network. We compared the bat movement algorithm and our proposal. We find that SHEM mobility manages the energy and connectivity consumption better than the simple bat movements.**

***Keywords*—algorithmic, energy, mobility, topology, connectivity, distributed, SHEM**

I. Introduction

Energy saving and lifetime improvement of the sensor node have been at the center of research on sensor networks recently [1–4]. Sensors use their energy primarily for calculation and data transmission purposes. The lifetime of a sensor depends essentially on the battery life. It is very much related to the activity of the sensor. In a WSN, each node plays the role of transmitter and router. An energy failure of a sensor can significantly change the topology of the network and impose a reorganization of the latter [5–7]. In the same way, the topology can evolve due to the mobility of the sensors or the arrival of new nodes [8–12]. Compared to static WSN, mobile sensor networks have more flexibility and capacity to cope with varying network conditions and environmental conditions.

The introduction of mobility to sensors improves not only their capacity and quality but also gives them flexibility to cope with the failure of a node. It is therefore necessary to manage the maintenance of this topology precisely at the time of the deployment, post deployment and redeployment of the sensor nodes. This will allow good connectivity and efficiency in the management of energy especially in mobile networks.

In this paper, we first discuss the problem of dynamic topology, and then return to the state of the art of topology control techniques. Then, we present our contribution SHEM, an algorithm of automatic maintenance of topology based on echolocation. Finally, we evaluate our method with experimental simulations.

II. Literature Review

In the works des auteurs [2], [13, 14], the topology can be described from three Ways: Strategies with mobile nodes, strategies with mobile relays, and event-based strategies.

Mobility of nodes [15]. It is the mobile nodes that change their location to better characterize the detection zone or to transfer data from the source nodes to the sink. These nodes can also be used to solve the detection cover problem. A reduced number of mobile nodes is deployed in submarine wsn. Submarine sensor nodes must be able to self-configure and adapt to the ocean environment. The sensors must be able to establish an autonomous network organization.

Mobile Relays. This is a particular case of mobility when data sinks are mobile. Rotation of collector mobile node by neighboring nodes [15, 16]: One solution is to use a collector (s) of measurements (eg a mobile robot) that will regularly visit disjointed clusters in order to restore discrete connectivity to reconstitute a coherent information system. Several relays in the nature (infrastructures) so that the fixed mobile link is carried out optimally between each sensor node and one of the relay nodes. The latter is not always the same over time, and a set of relays allows the routing of the packets to the well [17, 18]. Much research has been carried out in the field of well mobility using different parameters [19]. The mobile nodes being in a fixed relative position and assuming for some the transmitter sensor function, others for the transmitter and relay sensor function and for others the only relay function. The network then comprises an embedded part with a specific topology. The fixed mobile link is made between one of the mobile relay nodes (the latter is not always the same over time) and the well Camp [20–22]. The control of the topology, obtained by modifying the transmission power, will be used in particular to overcome certain physical constraints that do not make it possible to place the nodes in the best places.

Mobility of events [23]. Monitoring enemies requires mobile sensors. These nodes must be able to track the movement of troops and adverse troops.

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These different networks are faced with different challenges such as deployment, mobility management, location with mobility, navigation and control of mobile nodes, maintaining adequate detection coverage, Energy in locomotion, maintaining network connectivity and data distribution.

III. Materials and Methods

We propose a solution elaborated from the echo-localization whose principles we will detail in the following parts.

A. Principle of Echo-localization

Echo-localization consists of sending sounds and listening to their echo to locate, and to a lesser extent to identify the elements of an environment. It is used by some animals, including bats and cetaceans, and artificially with the sonar. It allows these animals to locate the elements of their environment (obstacles, cave walls or other cavities) and to locate their food (eg flowers or leaves of plants reflecting the echo of bats ultrasound) or their prey Where the view is ineffective because of the lack of light (night, cave, marine depth, turbidity of the water). Some blind people use echo-localization to locate obstacles. The use of hearing by the blind is noted by Denis Diderot in his Letter on the Blind for use by those who see in 1749. The first scientific experiments on the subject really begin in 1944 with the work of Michaels Supa and of his team which confirms that it is indeed the echo of the sounds they emit that allows the blind to determine the distance of certain obstacles. The echo-localization makes it possible to determine the distance of the obstacle, by the time elapsed between the emission of the sound and the perception of the echo. The transmitter with two ears measures the distance between the two receptions and deduces the direction of the target. The echo-localization indicates its size, the intensity of the echo (the smaller the target, the less it reflects the sound) and the duration of the echo (a large target does not produce a clear echo, but a longer echo as the receiver arrives from the more and more remote parts of the target). By measuring the Doppler shift, it also indicates the relative speed of the target relative to the transmitter. Finally, each type of target deforms the echo in a characteristic manner, allowing the transmitter to determine its nature; The beating of the wings of the insects, in particular, sign their presence in the echo. Depending on the use, it is not the same types of calls that are used, and notably the same frequencies. The process of echo-localization is very complex and has been studied in detail by many researchers [24]. The behavior can be modeled using three general rules:

- All bats use echo-localization to detect distance and they also guess the difference between food / prey and also the background of obstacles in an inexplicable way.
- Bats fly at random and set a minimum frequency, wavelength, and variable intensity to search for prey. They can automatically adjust the frequency of the emitted pulses according to the proximity of their target.
- Although the intensity may vary in several ways, we must assume that the intensity varies from a vertex to a constant minimum value.

We will then experiment with the network of sensors with antennas for each sensor. This section will show the importance of connectivity in energy gain to manage the dynamic topology of the mobile sensor network. We will use echo-localization as part of our contribution based on the bats displacement algorithm similar to particle swarm optimization algorithms.

B. Algorithm of the Bats

The algorithm of bats, whose denomination of origin is “Bat Algorithm” in English, is a very recent meta- heuristic. The first article about her was proposed in 2010 by [25]. It is based on the echolocation behavior of bats. Specifically, the species of micro-bats, which fly in flight by echolocation, can find, discriminate the different types of insects and avoid obstacles [26, 27]. The optimization by the technique of the bat (BAT) [28] is an approach inspired by the hunting behavior of the bats. During their flight and in order to avoid obstacles and target their prey, each individual beats a bisonar through his environment, the return of the echo makes it possible to identify the various objects of his entourage. Studies developed in this field have shown that the resonance of the emitted wave varies from a high value during a prospecting flight to a fairly low value with an increase in frequency when the bat detects and oblique in the direction of ’prey. It is assumed by intuition that these animals are able to differentiate their prey from other nearby obstacles, including nearby bats. Similar to the OEP, the BAT algorithm can be implemented for solving continuous optimization problems where the possible solutions can be represented by the geographical positions of the bats [29], [30]. In the “BAT Algorithm” algorithm, individuals are independent of each other in their movement. Its disadvantage is the lack of communication between individuals, forcing them to seek the best path, each in their own way without benefiting from the experience of the neighbors and consequently, consumes more useless resources.

C. SHEM Algorithm

We propose the SHEM algorithm whose study is naturally carried out within the framework of some realistic hypotheses which make it possible to limit its perimeter.

- Each of our sensors is mobile and has two antennas. An antenna for data capture, another frequency antenna to estimate the position and speed of the sensor to allow positioning of the sensor or other sensors for good connectivity
- All the sensors have the same communication radius and even sensitivity in reception, so the radio links are symmetrical (it is impossible to find practically nodes that have this characteristic therefore it is a working hypothesis).
- The physical layer model is ideal. A destination node C_i always receives without error a message from a sender node C_j when it is within its range, ie if the distance d (C_i; C_j) ≤ R_c, with R_c: communication radius, value included Between 1 and 100 meters with the technologies considered.

We will use the “Bat” algorithm while adding the construction of our network topology by the SHE algorithm. Distances calculated by the cluster algorithm will be used to steer the sensors as they move away or become close to maintain connectivity.

1) Description

The SHE algorithm consisted of setting up the clusters and designating the Head clusters by the base station. It allowed each sensor to self- evaluate itself in energy to continue residing in the cluster and the cluster head to allow a transition from its role to another with less energy to lose in the construction of clustering and in the choice of cluster head. Our second contribution uses the implementation of these clusters to enable the sensors to move randomly and unpredictably to minimize routing time, loss rate, power consumption and connectivity between network sensors. A node can send information to the cluster to which it belongs by using the maximum distance defined in the SHE algorithm. This is possible when the sensor realizes that its distance traveled is approaching this maximum distance which is indicative of the distance of the sensors from the other sensors. The transmitter will be able to do this at an amplification rate high. This message will allow the other clustering sensors to adapt their speed and direction of movement in order to remain in permanent contact and to ensure the connectivity of the network with the transmitter sensor. When it discovers an area of interest or wants to transmit data, it uses low amplification. If there is a change, it sends a message to all clusters head regarding its new position for an update of their data. In fact, we are based on the echo-localization at the second antenna which is a tracking system used by certain animals such as bats to keep connectivity in our clusters.

2) Our detailed algorithm

Our algorithm assumes that the sensor can follow its natural displacement and above all ask for a displacement. The movement of each sensor is free or can be guided by other sensors. It moves according to its current movement or suddenly changes direction such as moving a bat guided by its prey and sounds emitted by other bats. This movement can cause the other sensors (neighbors, CH) to move, depending on the sensitivity of the sensed data, the distance traveled and the data flow. At each instant t, each of the N sensors of the cluster has a _x_i position and a _v_i speed. During each movement, each sensor emits ultrasound with a power at a frequency $f_i \in [f_{min}: f_{max} = P_{min}: P_{Lmax}]$. Ultrasonic emissions are carried out in bursts according to the pulse rate $T_i \in [0: 1]$. When the node detects an area of interest, it emits more frequently ultrasounds with a low power (T_i large and P_i low). Conversely, when the sensor estimates its distance from the others without detection of an area of interest, emissions are less frequent but more powerful to allow the positions of the CH and its neighbor to be apprehended (to allow a junction by the displacement of the other nodes or requested its repositioning with respect to the other nodes).

3) Variables

P_{min}: minimum transmit power
P_{max}: maximum transmit power
P_i: transmission power of a sensor i
T_i: pulse rate for a sensor i
F_i: transmission frequency of a sensor i
V_i: sensor speed i
X_i: sensor position
iD: angle direction
α: transmit power reduction factor
γ: pulse rate readjustment factor
$U(\llbracket 1: N \rrbracket)$: function to choose a value in interval 1 and N.

4) Initialization

At initialization, by default, the sensors are distributed evenly in the search space (collector field). That is to say the construction of the clusters and designation of the CHs by the base station. The initial speed is generally zero. In most implementations, the transmission power is chosen in the interval [0:1]. That is, $P_{min} = 0$ and $P_{max} = 1$. The initial value of the transmission power and the pulse rate is often set to a value close to 0.5. In this case, a sensor has a 50 % chance of choosing a random displacement initially and in case of improvement of the best solution, to update its ultrasonic emission properties. It is also possible to initialize P_i and T_i randomly and differently for each node.

Algorithm 1: Initiate Pos Speed sensor ()

$T_{max} = 0.5$
for i = 1 to N do $X_i = U(S)$ ** The best path to reach the cluster-head (either direct if the energy is significant or several nodes to reach the CH).*
$V_i = 0$
$T_i = T_{max}$
$P_i = 0.5$
endfor

5) Moving sensors

As mentioned above, moving a sensor obeys its current movement or changes direction as the movement of a bat. To continue its current movement, a principle similar to that of swarm optimization is used. In this optimization, each bat is positioned (randomly or not) in the search space of the problem. Each iteration moves the bats according to 3 components: Begin itemize Item its current speed, Item Its best solution P_i, Item The best solution obtained in its neighborhood P_g. End itemize This gives the following equation of motion Clerc, Maurice (2005):

$$\vec{V}_{k+1} = w * \vec{V}_k + b_1 * \left(P_i - \vec{X}_k\right) + b_2 * (P_g - \vec{X}_k) \quad (1)$$

$$\vec{X}_{k+1} = \vec{X}_k + \vec{V}_{k+1} \quad (2)$$

Avec: w inertie
b_1 Randomly drawn in $[0, \phi 1]$
b_2 Randomly drawn in $[0, \phi 2]$.

In our situation, the new velocity is obtained by summing the current velocity and an external directional velocity vector. In the case of the basic form of the algorithm, this external directional speed is generally obtained by multiplying the transmission frequency f_i and the direction between the current position and the position of the best solution (obtained by putting the Cluster in place). The transmission frequency is generated uniformly in the interval $[f_{min}: f_{max}]$ and allows to control the rythm of the movement. The displacement is done by adding to the current position the new velocity represented by the Eq. (7). To change direction, the position is obtained from the current position of a randomly selected sensor (the cluster head or the neighboring sensor). This operation is represented by the Eq. (3). This position undergoes a random disturbance proportional to the average power of the ultrasound emitted by all the sensors. The Eqs. (3, 4) summarize these formulas. To control the choice of this or that movement strategy, the pulse rate T_i is used. The higher this rate, the more the sensor uses its current speed as well as the external information to define its new position. The lower the rate, the more random movements are allowed. This rate plays a role similar to that of the temperature in the simulated annealing and determines a balance between the exploitation of the current positions and the exploration of space. This is expressed by the Eqs. (5–7). The displacement phase is summarized by the following algorithm:

Algorithm 2: *Algorithm for moving the sensors*

for i = 1 to N do
if $U([0:1]) > t_i$
then

$$K = U(|1:N|) \quad (3)$$

$$\vec{x}_i = \vec{x}_k + \frac{\sum_{j=1}^{N} P_j(t-1)}{N} * U(|-1:1|)^D \quad (4)$$

else

$$f_i = U(|f_{\min}:f_{\max}|) \quad (5)$$

$$\vec{v}_i = \vec{v}_i + (\vec{x}_i - x^*) * f_i \quad (6)$$

$$\vec{x}_i = \vec{x}_i + \vec{v}_i \quad (7)$$

endif
endfor

6) Update of ultrasonic emission properties

If the solution position is better than the best solution currently known then the update of the ultrasonic emission properties is performed as a function of the probability P_i. In this case, the transmission power is reduced by a factor *alpha in*]0: 1[and the pulse rate T_i is increased and calculated according to the formula eqref impulsion with t the number of the iteration and as γ *in*]0: 1[. The progressive decrease of P_i causes a decrease in the probability of increasing T_i. The increase of T_i reduces the probability of resorting to a random displacement of the sensors and allows to progressively increase the exploitation of the solutions at the expense of the exploration of the space. The parameters γ and α are generally equal and have a value of 0.9. The step of the update is given by the following algorithm.

Algorithm 3: *Update of ultrasonic emission properties*

for i = 1 to N do
if $(U[0:1]) < P_i$ *et* $f(x_i) < f(x^*)$ *then*

$$P_i = \alpha * P_i \quad (8)$$

$$T_i = T_{max}(1 - e^{-\gamma * t}) \quad (9)$$

endif
endfor

7) Updating the best solution

The best solution that optimizes connectivity is updated by maintaining the best position of the sensors. At this level, since the sensors are in motion, the sensors can change their immediate neighbors in the event of an energy drop. So, the role of this part will be to calculate the position, update the coordinates of the immediate neighbor, the CH and try to keep the initialization topology.

Algorithm 4: *Updating the best solution*

for i = 1 to N do
if $f(x_i) < f(x^*)$ *then*
$x^* = x_i$
endif
endfor

8) Simulation parameters

In our simulations, it was necessary to determine sets of values for the following parameters:

- The number of nodes or agents must vary in the network, assuming that, in mobility and echo- localization, many nodes lead to high energy consumption. We will limit the number of nodes to thirty with fixed, mobile nodes and injection of other nodes.
- The velocity of the nodes must vary and be constant to see the effect on energy consumption for example.
- The distance between the nodes must vary by estimating that in echo-localization, the maximum distance is 5 m. The distance between the nodes varies between one and five meters.
- The direction of displacement is that of the sender node.

It was also necessary to combine these parameters in order to have representative experiments.

IV. Result and Discussion

The indicators chosen to evaluate the proposed algorithm can be:

- Number of disconnected nodes;
- The connection rate by referring to the percentage of nodes connected;
- The average distance between the nodes;
- The average number of neighbors;
- The energy consumption of the network as a whole.

By measuring the number of disconnected nodes over time and the connection rate, it is possible to directly assess the quality of the proposal and meet its primary objective of maintaining connectivity. In the connectivity measurements, a sensor measures the sensors that are within its transmission range. In other words, either a sensor is within the coverage area of a given sensor, or it is outside its transmission range. The two rate and distance indicators provide insight into how the nodes are distributed and how the proposed algorithm influences the movement of the nodes. Good results could be obtained by using not too large distances between the nodes so that their connectivity cannot be broken. This means that using the proposed solution the nodes can move away from each other, but not too much. However, the nodes should not keep too small a distance between them, which would imply a high concentration of nodes, which is not desirable either. The same reasoning holds for the fourth indicator, in which a very small number of neighbors, or not, would mean that the nodes are very sparse and then very prone to disconnect. However, too many neighbors would mean that the nodes are too concentrated, which is not desirable. In each scenario, four curves are presented. The first two compare “Bat” and “SHEM” without affecting the displacement. The other two compare “Bat” and “SHEM” with influence on the displacement. This is called the SHEM-D.

A. First Scenario

In this first scenario, we considered 10 nodes that will be mobile with the proposed movement of the bats. This scenario should allow us to measure the number of disconnected nodes and the connectivity rate.

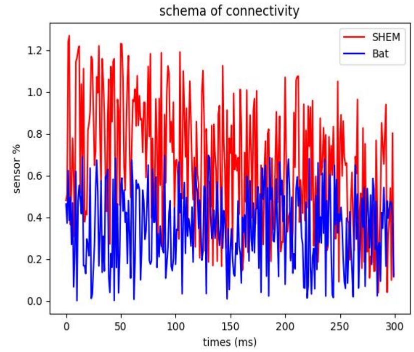

Fig. 1. Connectivity schema.

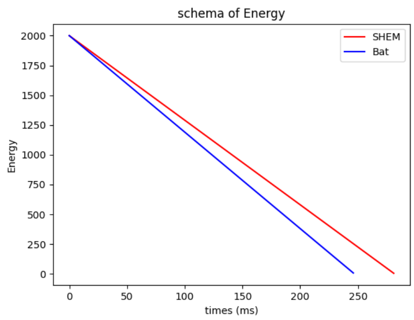

Fig. 2. Diagram of energy consumption.

1) Fixed speed and fixed distance

After several simulations of about 250 ms and 250 times, the Fig. 1 was obtained with a constant velocity for all nodes.

It shows the percentage of nodes connected between the “Bat” algorithm and the “SHEM” algorithm during the experiment. The different hollows are explained by the spacing of the nodes. The “Bat” curve has between 15 and 22 ms, between 98 and 100 ms, an almost zero percentage expressing the isolation of all the nodes of the network. Between 239 and 250 ms, this curve gives a very low rate which is explained by the death of the nodes of the network. This loss of nodes is expressed by all the curves with a progressive loss of the connection rate in the set. On the other hand, there is a strong connectivity over time by the SHEM curve whose lowest rate exceeds 10.

Curve 2 shows the evolution of energy in the whole. It can be seen that the “SHEM” algorithm consumes less than the “Bat” algorithm over time. This is explained by the reduction in the distance of sending and also the maintenance of the connectivity Life of the network. It shows a considerable decline for “Bat”. This can be explained by the isolation of the nodes and considerable remote communication. This curve shows a random displacement that consumes more energy than the SHEM algorithm.

Considering the change of direction, we obtain Fig. 1, Figs. 2–4 showing the connectivity and evolution of energy over the life of the network. Considering the direction shows an increase in connectivity and also a slight gain in energy which passes from 870 (SHEM) to 905 (SHEM-D). This is explained by a high communication number and also with the reduction of the communication distance.

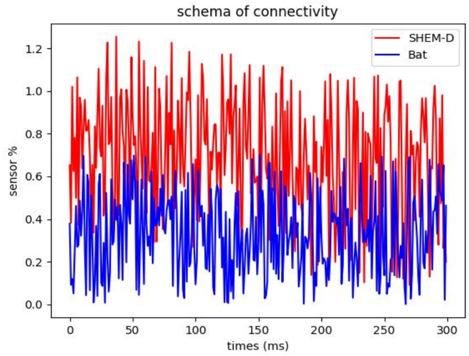

Fig. 3. Connectivity schema.

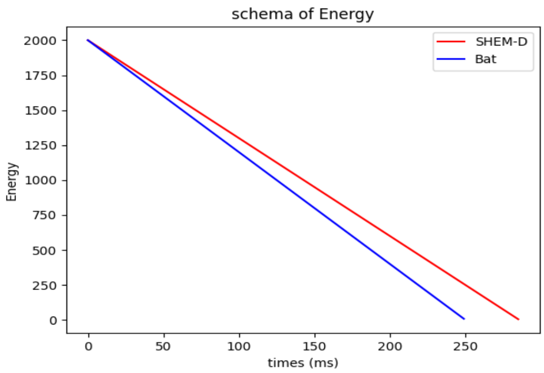

Fig. 4. Diagram of energy consumption.

2) At progressive speed and variable distance

We pushed the first scenario further by modifying the speed of each sensor as a function of the speed of the message transmitter. The speed of the transmitter is added to the old sensor speed. This allowed to have a dynamic speed with a maximum speed limitation. With this, the connectivity rate has increased.

Fig. 5 illustrates this connectivity. The troughs of the curve are explained by the spacing of certain nodes during the life of the network. These nodes move away due to their individual movement. There is an increase in the minimum connectivity rate compared to the first experiment. This means that speed plays a significant role in connectivity. The diagram shows a marked improvement in connectivity with “SHEM” compared to “Bat”. The speed management proves by this scheme that the connectivity can be maintained by playing on these parameters. This leads to a reduction in the energy consumption expressed in the diagram of Fig. 6.

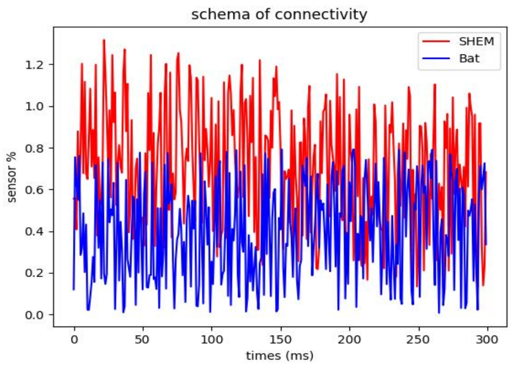

Fig. 5. Connectivity schema.

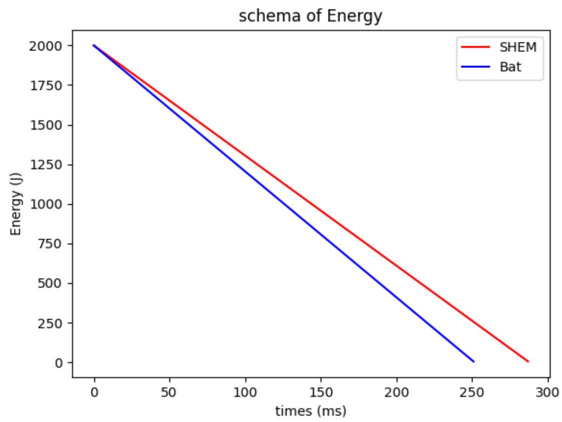

Fig. 6. Diagram of energy consumption.

There is a loss of connectivity expressed by a few peaks between 27 and 40 ms and also between 84 and 90 ms.

This modification has played a major role in the energy consumption expressed in Fig. 6, which has decreased from the above assumption where the velocity is constant. This is due to a rapid reduction in the distance of messages sent.

Taking the direction into account, we obtain Figs. 7, 8 which give almost the same connectivity and consumption patterns as before. With this configuration, connectivity was further improved with a small increase in energy gain with 1002 for SHEM and 1060 for SHEM-D.

B. Second Scenario

In the second scenario, we considered 20 nodes and rendered 10 mobile nodes.

1) Fixed speed and fixed distance

Using the same simulation time, Fig. 7 is obtained with a greater degree of connectivity than the first scenario. This is explained by the influence of fixed nodes that provide some connectivity with the isolated nodes. The isolated nodes approach the other nodes thanks to the fixed nodes which act as relays between the isolated nodes and the mobile nodes. There are also hollows explaining the isolation of certain nodes in the network.

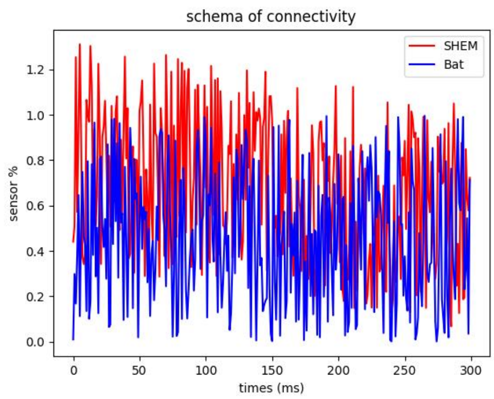

Fig. 7. Connectivity schema.

At the level of this figure, we note an increase in the minimum connectivity rate and a maximum rate close to 100 % for "SHEM". "Bat" still has some spikes of connection loss between all nodes.

In terms of consumption, Fig. 8 shows a decrease in energy consumption for both algorithms. The greater the number of sensors, the greater the number of calls for connectivity. The experiment was continued with the management taken into account and which leads to the diagrams in Figs. 9, 10. These curves show management's interest in power consumption and connectivity. The connectivity rate has increased and energy consumption has decreased. SHEM is 1004 and SHEM-D is 1078.

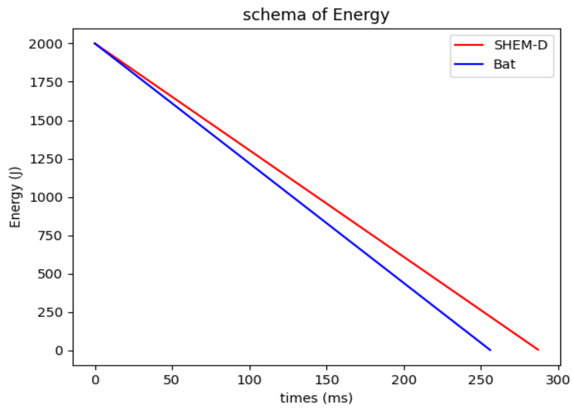

Fig. 8. Diagram of energy consumption.

Fixed sensors ensure connection but also shorten communication distances to reduce energy consumption. As before, it is found that "SHEM-D" saves energy better than "SHEM" and "Bat".

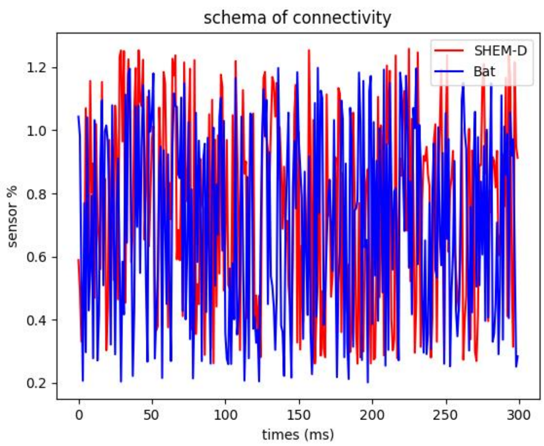

Fig. 9. Connectivity schema.

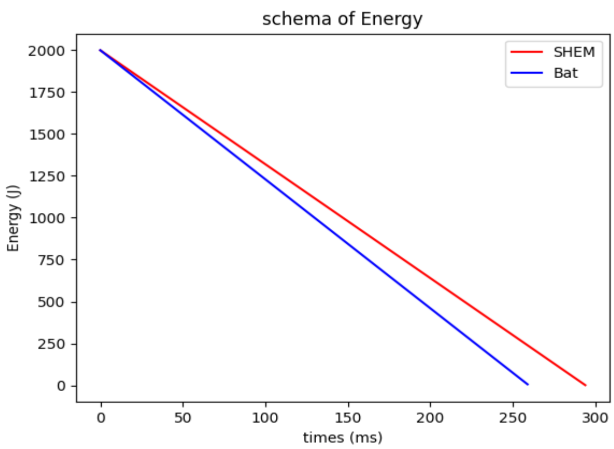

Fig. 10. Diagram of energy consumption.

2) At progressive speed and variable distance

We continued this experiment by varying the speed of the sensors as in the first scenario.

This allowed us to have Fig. 11 indicating a high connectivity rate in this scenario. This rate is explained by the variation of the speed which makes it possible to bring the nodes closer together. The closer the sensors are, the lower the power consumption in terms of the emission distance. But the number of communications increases to maintain this connectivity. This increases the overall consumption of the nodes 15.

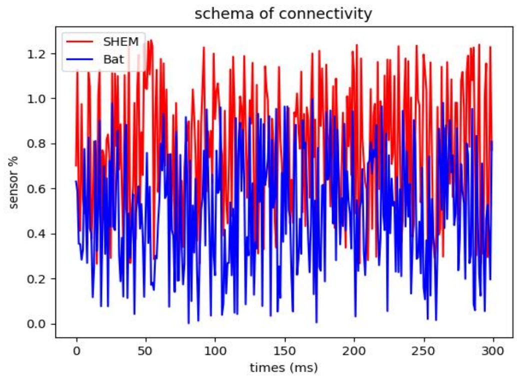

Fig. 11. Connectivity schema.

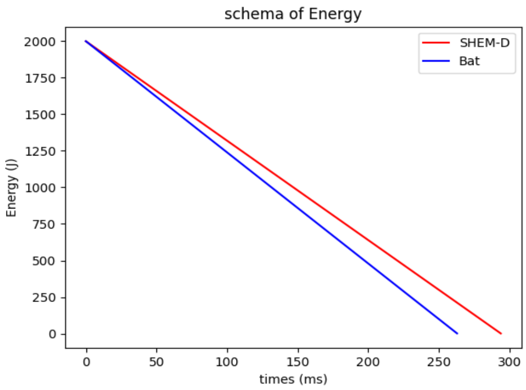

Fig. 12. Diagram of energy consumption.

Fig. 12 also shows a decrease in the energy consumption in the variable speed sensor array. Figs. 13 and 14 take into account the redirection of moving sensors. They show an improvement in connectivity and consumption which goes from 1005 for SHEM to 1103 for SHEM-D.

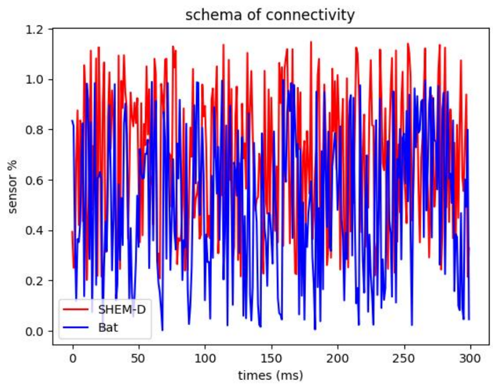

Fig. 13. Connectivity schema.

We find in the second scenario that the fixed nodes that act as relays have improved the connectivity rate and the energy consumption compared to the first scenario.

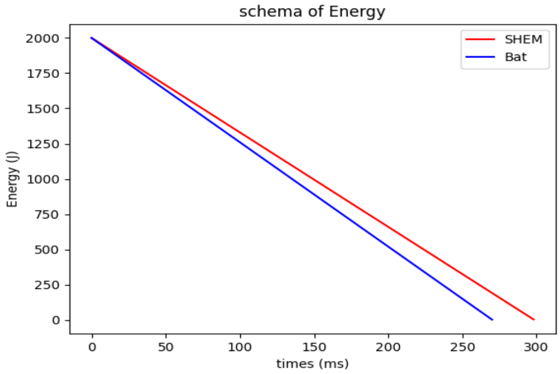

Fig. 14. Diagram of energy consumption.

C. *Third Scenario*

In this scenario, we decided to increase the number of sensors. Under the same conditions as the two previous scenarios, the insertion of new sensors to the number of ten maintains and further increases the connectivity of the network. Fig. 15 shows this increase in connectivity. Like the other scenarios, we observe the isolation of certain nodes of the network by the troughs of the curves. Despite the insertion of the nodes, the connectivity loss for the "Bat" algorithm, for example between 109 and 130 ms, is observed. In addition, Fig. 16 also shows a regressive decrease in energy but with an energy gain compared to other scenarios. An increase is observed around 170 ms and is due to the insertion of new nodes. The curves of Figs. 17 and 18 are obtained under the same conditions while playing on the direction.

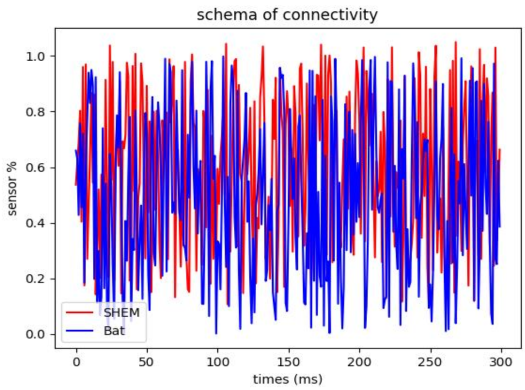

Fig. 15. Connectivity schema.

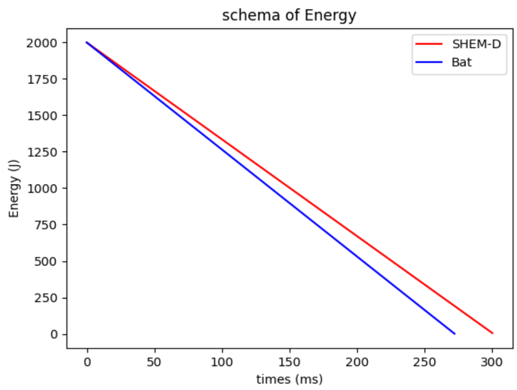

Fig. 16. Diagram of energy consumption.

This further demonstrates the role of redirection on connectivity and energy consumption. The values for these data increased from 1006 to 1130.

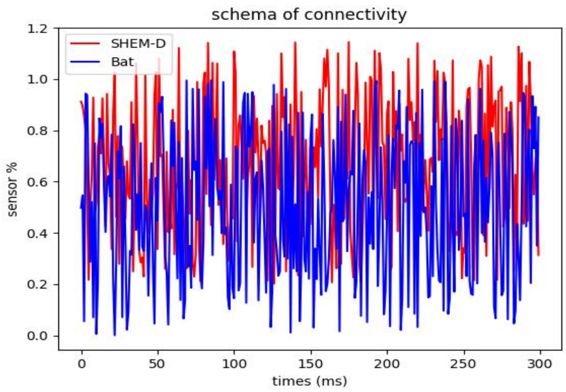

Fig. 17. Connectivity schema.

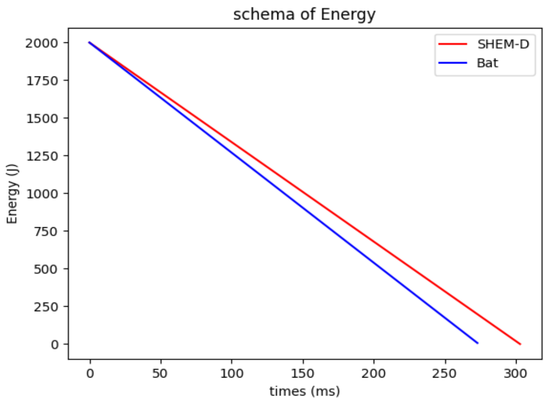

Fig. 18. Diagram of energy consumption.

V. Conclusion

In this study, we focused on mobility and connectivity based on the lifestyle of bats. The implementation of our algorithm under the Netlogo simulator allowed us to extract some results by simulation and to evaluate the effectiveness of our echo localization approach. These results show the advantage of displacement using echo-localization to ensure fault tolerance, connectivity in a wireless sensor network. The exploitation of the group mobility of bats makes it possible to extend the lifetime of the network. This treatment is done in a distributed manner. This aim is achieved by implementing a mechanism of topology dynamicity, and the displacement of some mobile nodes is indispensable. To conclude, we can note from these simulations that the results obtained show the good behavior of our algorithm and encourage us to orient our future research work by favoring the use of the displacements of the bats and the communication by echo localization.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

This work was developed under the supervision of Christophe LANG who was my thesis co-director.

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