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Novel Wireless Sensors Network Routing Approach for Industrial Process Control

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***Abstract*— The present work treats the problem of routing data within a wireless sensors network (WSN) for industrial process control. Our application interests British Gas to monitor the level of propane in a tank. The considered methodology is based on the algorithm CSMA / CA Slotted to access the medium, the processing algorithm measures the volume of propane to exploit failing sensors and intelligent routing algorithm transmission value through the base station while ensuring minimizing energy consumption and maximizing the life time of nodes. The combination of these mechanisms gives birth to a new approach which has been applied to a WSN installed in the industry in order to analyze the performance of the techniques developed for the quality of service Qos, the energy conservation and extension of life.**

***Index Terms*— Wireless Sensors Network, Algorithm CSMA / CA Slotted, Processing algorithm, Routing algorithm, Energy conservation, Quality of service Qos, Elongation of life.**

I. INTRODUCTION

The current need for monitoring and supervising the execution of a real-time process promotes the use of wireless sensor networks (WSN). This type of network is facilitates the diagnosis and control of industrial systems. It consists of several intelligent multifunctional and low-cost miniature components called sensor nodes. These nodes are capable of acquiring, storing and processing data. The transmission of the collected information to one or more collection points is done through a radio interface ZigBee. This technology which is based on standard communication IEEE.802.15.4 is a major challenge for the development of sensor networks [1]. This standard promotes low power consumption, low cost and low throughput despite the dense deployment of nodes which is essential to the success of an infinite number of paths. This certainly causes the complexity of routing.

Generally, there are well recognized and adopted approaches to routing in the fields of automation and industry such as AODV and DSR [2]-[7] they both allow updating of the routing table but they do not consider energy consumption. The most common approach to routing is called "Dijkstra's work" [8]. The disadvantage of this technique is the determination of a single optimal route between the source and the destination. This path is used so often that it leads to the failure of the initial nodes. In this case, the possible solution is to define an efficient routing solution that has the tendency to save energy and prolong the life of the network. This routing solution enables messages to be transmitted through the network, to take several paths in order to reach their destinations without losing hastily nodes. The objective of our work is to create a referral methodology to oversee the development of the volume in a tank of propane.

In this context, we will deploy a wireless sensor network in the industry. This requires the development of a model and a communicative architecture adapted to the industrial scope. In addition, we synthesize a strategy for processing the data from the sensors while eliminating measures produced by the failing sensors. This strategy may only be feasible after the data transmission phase between sensor nodes and processing node also called sink. To manage this communication traffic and avoid the phenomenon of collision we adopted the CSMA/CA technique [9]. In addition, we have proposed a new approach to choose the optimal path among all possible routes between the sink node and the destination node while respecting the minimization of energy consumption and the increase in the lifetime of nodes whatever the network density is [10]. Finally, the coherent assembly of all these techniques gives birth to an algorithm which allows the supervisor to view in real time on a graphic interface reliable and accurate measurements of gas' volume in the tank.

II. OVERVIEW ON IEEE 802.15.4

The IEEE.802.15.4 standard defines two bottom layers of the stack protocol which are the physical layer and the data link layer called MAC. One of the main features of the MAC layer is to define two modes of access to the medium [11]. The first is a not tag mode that is rarely used because it cannot guarantee a delivery time of messages. The second is a tag mode which is the object of our study in which IEEE.802.15.4 protocol uses a superframe structure shown in figure 1.

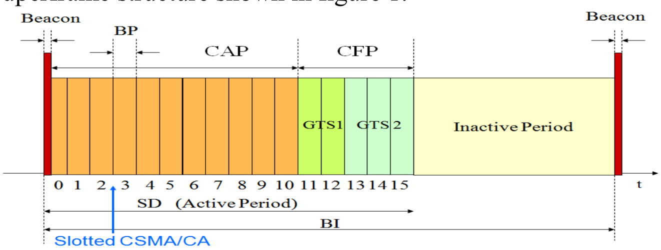

Fig. 1. Structure of the superframe 802.15.4

This structure starts with a tag generated in a periodic manner with a specific node called coordinator. Between two tags we defined two parts:

- An inactive part in which the nodes are in a standby mode.
- An active part is divided into two periods: the CAP (Contention Access Period) where nodes can communicate using the CSMA-CA algorithm to avoid collisions, and CFP (Contention Free Period) during which the communication done through the slots or time slots (GTSs: Guaranteed Time slots) are reserved by the nodes during the CAP [12].

III. CONTENTION ACCESS PERIOD (CAP)

To ensure receiving all the data sent by the sensor nodes and reducing packet loss that comes from collisions between nodes of the same level, the frames in the CAP segment must use the technique for CSMA/CA Slotted to access the medium [13]. The algorithm CSMA / CA described is reflected in the following chart [14]:

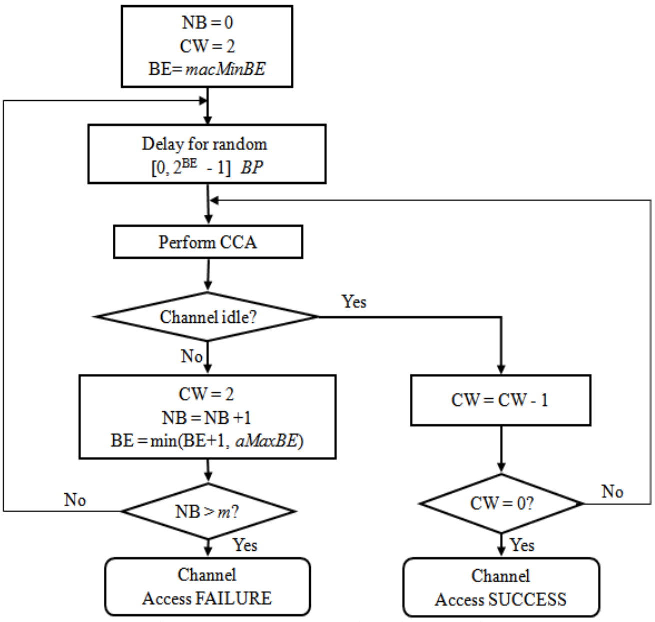

Fig. 2. IEEE 802.15.4 Slotted CSMA / CA.

IV. COMMUNICATION PROCEDURE

The exchange of messages between nodes occurs in a scenario presented in figure3 and detailed as follows: Initially, the sensor nodes receive "Beacon" frames generated by the coordinator node to ensure synchronization. Then, each sensor node must run the algorithm CSMA / CA Slotted to avoid data loss. These packets are encapsulated in PPDUs (PHY Protocol Data Unit), each having the following elements:

- A synchronization header length of 5 bytes SHR.
- A header containing the PHY frame length of 1 byte size.
- Useful data that occupy 4 bytes and overhead generated by the MAC sublayer of size 25 bytes.

Following receipt of the data packet, the node coordinator sends an ACK packet size of 11 bytes [13].

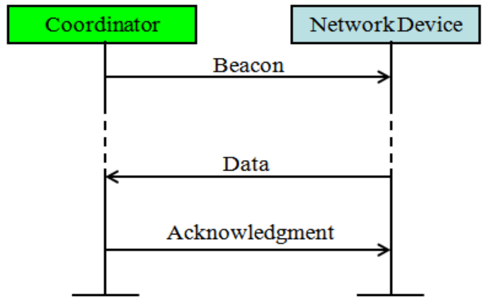

Fig. 3. Ideal communication mechanism (without collision)

V. THE PROPOSED ANALYTICAL MODEL

In our application we developed a model of wireless network which aims to ensure the functions of surveillance and monitoring of propane level in the tanks continuously. It is composed of 21 nodes that are deployed in a mesh topology (Figure4) which depends on the industrial infrastructure. This model is based on an architecture composed of four levels: The lower level (layer 3) includes 6 industrial sensor nodes installed on the device from the tank to monitor and control the level of propane. Each type of sensor has requirements in terms of delay, throughput, and detection mechanism. The most common techniques used for detecting the level of the fluid in an industrial process are: the float sensor, the capacitive sensor, the resistive sensor, the infrared sensor, the ultrasonic sensor and the conductive detector. The secondary level (layer 2) is formed by central nodes that can improve the quality, the reliability of measurements collected and the transfer of information to intermediate nodes located at the tertiary level (layer 1) and provide a better coverage. The top level (layer 0) consists ofin a node supervisor also called base station usually located in a control room.

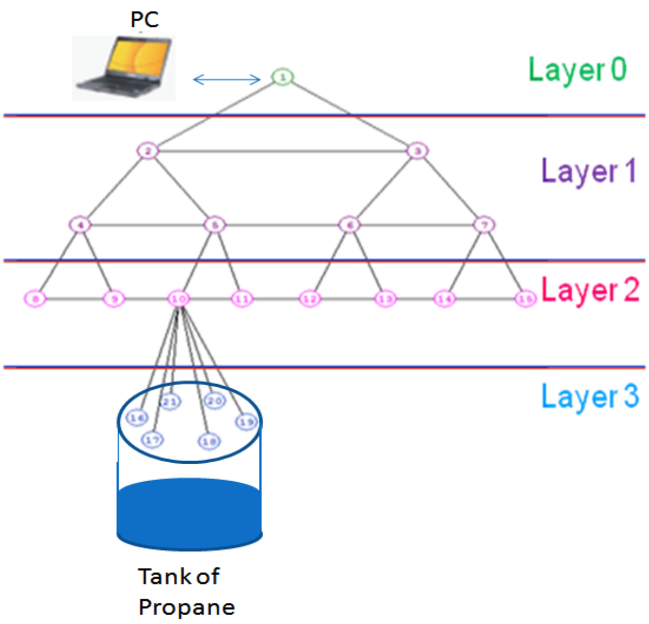

Fig. 4. Diagram of the proposed model.

VI. PROCEEDING ROUTING MESSAGE

In the wireless sensor network the central node aggregates the data received from sensor nodes to sort the measurements collected by healthy nodes to calculate their medium and send it to the base station along the optimal path. To achieve a reliable network we must ensure that when a small percentage of nodes fail it should not induce the failure of the entire system. So the proper functioning of a sensor is mainly due to three key aspects: the reliability of measurements collected about the fluid level in the tank, the reliability of communication links between the nodes and also the reliability of the analysis of the data collected at the collector. At first, we must create a method that must be implemented in the coordinator node to extract false readings.

A. Processing technique

This treatment technique involves the collection of all measures which are represented in list L1 and detected by the various sensors whose identities are mentioned in list C1. Then it comes to calculating the error between the current values with all steps above it. If this difference is less than a given tolerance e then the index of these two nodes is added to list L2. This step is repeated until the end of list L1. We follow list L2 and record the number of occurrences of each index in list L3. Then extract the index nodes whose repetition number is equal to a maximum value appearing in list L3. These nodes correspond to the healthy sensors while the remaining ones are failing. To validate our approach we conducted a test on the following measures:

Identities of the sensors: C1 = [16 17 18 19 20 21]

Measurements detected: L1=[2.59 2.508 2.527 2.58 2.7 2.506]

Tolerance range: e=0.0025

List of passage: L2 = [17 18 16 19 17 21 18 21]

List of appearance:
$$\begin{array}{ccccc} 17 & 18 & 16 & 19 & 21 \\ \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \end{array}$$
$$L3 = \begin{bmatrix} 2 & 2 & 1 & 1 & 2 \end{bmatrix}$$

Healthy sensors: C2 = [17 18 21]

Failing sensors C3 = [16 19 20]

This test shows that the phase of data processing is validated. Therefore the coordinator node must calculate the average value of the data collected by the sensors and the sound returned to a base station.

B. Multipath routing technique

The manual determination of all possible routes between the source node and the destination node is almost impossible in the case of high-density network. For this, we proposed a-generic-optimal robust program, able to extract all paths connecting the sink node to the target node. At the beginning, the user must complete the square matrix of dimension $h * h$, such that h is the number of nodes, including its elements represent the distance between two neighboring nodes. The graph is undirected which results in a symmetric matrix having the following form:

$$M(i,j)=M(j,i)=\begin{cases} d(i,j) & \text{if } i \neq j \text{ and i and j are two adjacent nodes} \\ 0 & \text{if i=j or i and j are not two adjacent nodes} \end{cases} \quad (1)$$

Then it comes to fixing the source node *s* and destination node *d*.

The following step is to go online $M(s,j)_{1 \le j \le h}$ and retrieve the column index where $M(s,j) \neq 0$. This approach allowed us to determine all the nodes in the vicinity of the source node *s*. Each intermediate node plays a dual receiver with respect to the source s and transmitter relative to other nodes that are in their neighborhoods and that are different from s. In other words, we will translate the source name to the last completed nodes. So we must go through all these neighboring nodes to determine others which are in their litters. Note that the number of paths will be duplicated according to the number of neighborhoods while respecting the condition of passing through a node only once in each path. The best results obtained were reached with the repetition of the above steps either by achieving the destination or when by stumbling on the following condition $M(s,j)=0 \; \forall 1 \le j \le h$. A final test is added to eliminate the cases where the last node does not converge to the recipient. To validate our approach, we simulated the algorithm which has been programmed in Matlab version 7.0 and shows the different routes that connect the sink node to recipient node. The simulation results illustrated in the matrix L of dimension $k * z$, such that k is equal to 196 and shows the number of possible paths which link the node 10 to node 1.

$$L = \begin{array}{c} L_1 \rightarrow \\ L_2 \rightarrow \\ L_3 \rightarrow \\ L_4 \rightarrow \\ \vdots \\ L_{95} \rightarrow \\ L_{96} \rightarrow \\ L_{97} \rightarrow \\ L_{98} \rightarrow \\ \vdots \\ L_{193} \rightarrow \\ L_{194} \rightarrow \\ L_{195} \rightarrow \\ L_{196} \rightarrow \end{array} \begin{bmatrix} 10 & 5 & 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 10 & 5 & 2 & 3 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 10 & 5 & 4 & 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 10 & 5 & 4 & 2 & 3 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ & & & & & & \vdots & & & & & & & & \\ 10 & 9 & 8 & 4 & 2 & 5 & 6 & 13 & 14 & 7 & 3 & 1 & 0 & 0 & 0 \\ 10 & 9 & 8 & 4 & 2 & 5 & 6 & 13 & 14 & 15 & 7 & 3 & 1 & 0 & 0 \\ 10 & 9 & 8 & 4 & 2 & 5 & 11 & 12 & 6 & 3 & 1 & 0 & 0 & 0 & 0 \\ 10 & 9 & 8 & 4 & 2 & 5 & 11 & 12 & 6 & 7 & 3 & 1 & 0 & 0 & 0 \\ & & & & & & \vdots & & & & & & & & \\ 10 & 11 & 12 & 13 & 14 & 15 & 7 & 6 & 5 & 2 & 1 & 0 & 0 & 0 & 0 \\ 10 & 11 & 12 & 13 & 14 & 15 & 7 & 6 & 5 & 2 & 3 & 1 & 0 & 0 & 0 \\ 10 & 11 & 12 & 13 & 14 & 15 & 7 & 6 & 5 & 4 & 2 & 1 & 0 & 0 & 0 \\ 10 & 11 & 12 & 13 & 14 & 15 & 7 & 6 & 5 & 4 & 2 & 3 & 1 & 0 & 0 \end{bmatrix}_{(S=10;D=1)}$$

C. Energy consumption in wireless sensor network

Energy expenditure occurs during the transfer of the message between nodes. This consumption differs from the transmitting node, the receiving node and the intermediate node. Indeed, to perform a transmission we must take the following parameters into consideration:

TABLE I. USEFUL SIMULATION PARAMETERS

Symbol	Quantity	Value
N_{Symbol}	number of bits by symbol	4 b
N_O	number of bits by byte(octet)	8 b
S_b	size of the weft marks out	21 o
S_d	size of the weft of data	17+n o
S_{Ack}	size of the weft of acquittal	11 o
D	flow	250kb/s
P_{idle}	Power consumption in listening mode	135×10^{-5} W
P_e	Power consumption in transmission mode	81×10^{-3} W
P_{recept}	Power consumption in receive mode	100×10^{-3} W
P_{return}	Switching power from transmission to reception and vice versa	10^{-5} W
T_{Symbol}	Duration of a symbol	N_s/D s
Tb	Duration of a weft mark out	S_bN_O/N_ST_{symbol} s
T_d	Duration of a weft of data	S_dN_O/N_ST_{symbol} s
T_{Ack}	Duration of a weft of acquittal	$S_{Ack}N_O/N_ST_{symbol}$ s
T_{return}	Switching delay from transmission to reception and vice versa	144×10^{-6} s
$T_{Backoff}$	Duration of a unit of Backoff	320×10^{-6} s
T_{CCA}	Duration of a Clear Channel Assessment	128×10^{-6} s
T_{AA}	Duration of a latency	864×10^{-6} s
C	celerity	3×10^{8} m/s

o = octet, kb = kilobit, b = bit, V = volt, s = second, W = Watt, m = meter.

The amount of energy required to provide communication involves the durations of the beacon frame, the data frame and the acknowledgment frame, as well as the timeout "backoff", the propagation delay, and the rollover or transition time between the two operating modes i.e. the transmission and reception modes.

The time required for communication T_c in each node with index L(j,i), such as $1 \le j \le k$, $1 \le i \le z$ and $L(j,i+1) \ne 0$ is:

$$T_c(j,L(j,i)) = T_b + 2T_{return} + T_{Backoff} + 2T_{CCA} + T_{Ack} + T_d + 2\left(\frac{3}{2C}M\left(L(j,i),L(j,i+1)\right)\right) \quad (2)$$

The useful energy emission E_e is expressed as follows:

$$E_e(j,L(j,i)) = T_b \times P_{recept} + 2T_{return} \times P_{return} + \left(T_{Backoff} + 2T_{CCA} + \left(\frac{3}{2C}M\left(L(j,i),L(j,i+1)\right)\right)\right)\times P_{idle} + T_d \times P_e + T_{Ack} \times P_{recept} + \left(\frac{3}{2C}M\left(L(j,i),L(j,i+1)\right)\right)\times P_e \quad (3)$$

However, if the node index L(j,i) is a recipient, the fundamental energy at the reception Er is:

$$E_r\left(j,L(j,i)\right) = T_b \times P_e + 2T_{return} \times P_{return} + \left(T_{Backoff} + 2T_{CCA} + \left(\frac{3}{2C}M\left(L(j,i\text{-}1),L(j,i)\right)\right)\right)\times P_{idle} + T_d \times P_{recept} + T_{Ack} \times P_e + 2\left(\frac{3}{2C}M\left(L(j,i\text{-}1),L(j,i)\right)\right)\times P_e \quad (4)$$

After the transmission of the data packet of the transmitting node waits for the acknowledgment frame for a period T_{AA} equal to 32 or 512 symbols. If the waiting time expires, the node takes a new backoff by doubling the contention window. This step is repeated until no collision is detected. In this case the time required for communication T_c is equivalent to:

$$T_c(j,L(j,i)) = T_b + 2T_{return} + T_{Backoff\_total} + N_{CCA}T_{CCA} + \left(N_{Backoff} - 1\right)T_{AA} + T_{Ack} + N_{Backoff}T_d + 2\left(\frac{3}{2C}M\left(L(j,i),L(j,i+1)\right)\right) \quad (5)$$

The energy consumed by an issuer node E_e becomes:

$$E_e(j,L(j,i)) = T_b \times P_{recept} + 2T_{return} \times P_{return} + \left(T_{Backoff} + N_{CCA}T_{CCA} + \left(N_{Backoff} - 1\right)T_{AA}\right)\times P_{idle} + \left(\frac{3}{2C}M\left(L(j,i),L(j,i+1)\right)\right)\times P_{idle} + N_{Backoff}T_d \times P_e + T_{Ack} \times P_{recept} + N_{Backoff}\left(\frac{3}{2C}M\left(L(j,i),L(j,i+1)\right)\right)\times P_e \quad (6)$$

While the useful energy for the receipt E_r is written in the following form:

$$\begin{aligned} & E_r(j,L(j,i)) = T_b \times P_e + 2T_{return} \times P_{return} + \\ & \left(T_{Backoff} + N_{CCA}T_{CCA} + \left(N_{Backoff} - 1\right)\left(T_{AA} + T_d\right)\right) \times P_{idle} + \\ & N_{Backoff}\left(\frac{3}{2C}M\left(L(j,i\text{-}1),L(j,i)\right)\right) \times P_{idle} + T_d \times P_{recept} + T_{Ack} \times P_e + \\ & 2\left(\frac{3}{2C}M\left(L(j,i\text{-}1),L(j,i)\right)\right) \times P_e \end{aligned} \quad (7)$$

However, it turned out that each node has a sleeping time Ts during which it remains inactive. This is given by the following equation:

$$T_s\left(j,i\right)_{1\le j\le k,1\le i\le h} = \left(\sum_{d=1}^{h} T_c\left(j,d\right)\right) - T_c\left(j,i\right) \quad (8)$$

The energy consumed by a node during the period of sleepiness E_s is equal to:

$$E_s\left(j,i\right)_{1\le j\le k,1\le i\le h} = T_s\left(j,i\right)_{1\le j\le k,1\le i\le h} \times P_s \quad (9)$$

So the total energy consumed E_c by a node i, with $1\le i \le h$, in a network is calculated as follows:

$$\begin{aligned} E_C\left(j,i\right)_{1\le j\le k,1\le i\le h} = E_e\left(j,i\right)_{1\le j\le k,1\le i\le h} + E_r\left(j,i\right)_{1\le j\le k,1\le i\le h} + \\ E_s\left(j,i\right)_{1\le j\le k,1\le i\le h} \end{aligned} \quad (10)$$

Here, a selection technique was proposed for selecting an optimal path which has the tendency to save energy and prolong the network life.

D. Optimal path selection technique

To optimize energy consumption, a metric based on the combination of the two following criteria has been proposed: The first was to minimize the energy consumed by all nodes during message routing. So after extracting all possible paths connecting the source to the destination, we calculated E_{Cj} the amount of energy consumed in each case j. The chosen path is the one with minimum energy consumption.

$$E_{C_j} = \sum_{i=1}^{h} E_C(j,i) \quad (11)$$

$$R_{opt} = \min\left(E_{C_{j\in[1..k]}}\right) \quad (12)$$

where R_{opt}: the optimum road characterized by a minimum energy consumption.

The second criterion allows the user to extend the lifetime of the whole network by calculating $E_{rem_{i\in road\ j}}$ which is the remaining energy in each node i and in every possible way j to determine the index of the node in which the battery depletes first. The removal of nodes causes an increase in energy consumption since the distance between nodes becomes longer. So to avoid the quick death of nodes, we chose the route that has the maximum cost among all possible routes.

$$R_{opt} = \max\left(\min\left(E_{rem_{i\in road\ j}}\right)\right)_{j\in[1..k]} \quad (13)$$

The combination of these two criteria is only possible when they are of the same type, so we have to change the second criterion as follows:

$$E_{rem\min_j} = \frac{1}{\min\left(E_{rem_{i\in road\ j}}\right)} \quad (14)$$

$$R_{opt} = \min\left(E_{rem\min}\right)_{j\in[1..k]} \quad (15)$$

Solving the problem of consistency, the difference between high values of the two criteria is based on a classical algorithm that transforms these results to percentage values.

$$E_{C_j} = \frac{\sum_{i=1}^{h} E_C(j,i)}{\sum_{j=1}^{k}\sum_{i=1}^{h} E_C(j,i)} \quad (16)$$

$$E_{rem\min_j} = \frac{\dfrac{1}{\min\left(E_{rem_{i\in road\ j}}\right)}}{\sum_{j=1}^{k}\dfrac{1}{\min\left(E_{rem_{i\in road\ j}}\right)}} \quad (17)$$

Thus, the assessment technique proposed is based on the sum of the weights of the two criteria to optimize energy consumption, is expressed as follows:

$$MP_j = \alpha E_{C_j} + \beta E_{rem\min_j} \quad (18)$$

where $\alpha + \beta = 1$

For $\alpha = 0$, the metric is purely based on the increase in life. For $\beta = 0$, the metric depends on the sole criterion of the minimization of energy consumption.

Our work is based on a mixed and balanced metric with two weighing coefficients between the energy criterion $\left(\alpha = 0.5\right)$ and the life criterion $\left(\beta = 0.5\right)$. This factor α favors minimal energy consumption calculated from the shortest path to each exchange selected by our algorithm. However, its complementary β significantly improves the lifetime of the network (exhausted batteries of the nodes = nodes death) with compromises to alternate routes even if they are not the shortest paths.

VII. Simulation Results

For the evaluation and validation of our method we used a simulation prototype with "software-programming-Matlab version 7.0". To follow the flow of information in the network, we implemented a delay algorithm whose to specify the arrival time of the message in each node. After each sampling period a series of measures has been detected by the sensor nodes. These values must be transferred to the sink node after a random waiting time. The termination time of the collection phase of all data corresponds to the time of receipt of information generated by the last sensor node which has a maximum backoffs time. From this moment, the sink node decides to transfer the average volume to the base station along the optimal path. We consider Figure 5 which shows the evolution of detected measures within each sensor.

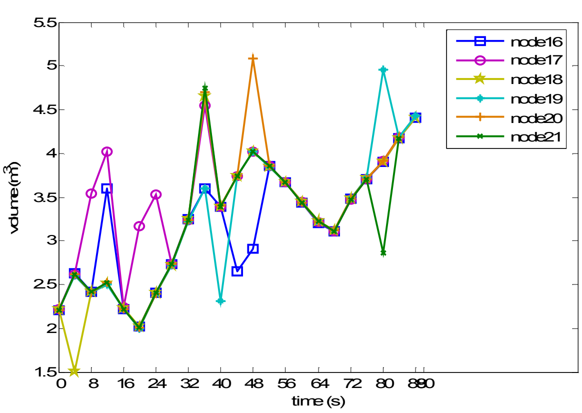

Fig. 5. The measurements detected by the various sensors.

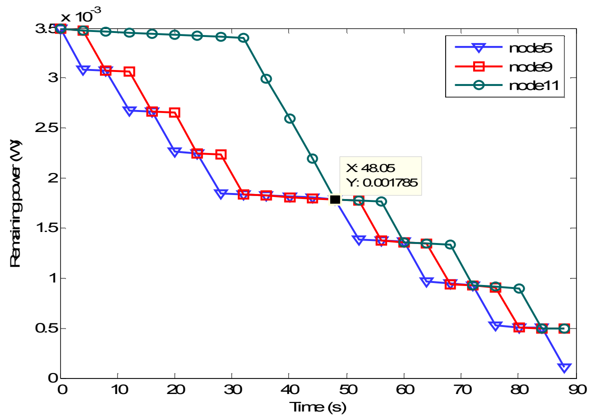

Fig. 6. Change in the remaining energy in the nodes 5, 9 and 11.

The flow of information is provided as shown in the vector Chosen_roads below:

$$
Chosen\_roads = \begin{bmatrix}
L1 \\
10 \quad 5 \quad 2 \quad 1 \\
L1 \\
10 \quad 9 \quad 4 \quad 2 \quad 1 \\
\vdots \\
L1 \\
10 \quad 11 \quad 12 \quad 6 \quad 3 \quad 1 \\
\vdots \\
L1 \\
10 \quad 5 \quad 2 \quad 1 \\
L1 \\
10 \quad 9 \quad 4 \quad 2 \quad 1 \\
L1 \\
10 \quad 11 \quad 12 \quad 6 \quad 3 \quad 1 \\
\vdots \\
L1 \\
10 \quad 5 \quad 2 \quad 1 \\
L2 \\
10 \quad 9 \quad 4 \quad 2 \quad 1
\end{bmatrix}
$$

With: $L1 = \begin{bmatrix} 16 & 10 \\ 17 & 10 \\ 18 & 10 \\ 19 & 10 \\ 20 & 10 \\ 21 & 10 \end{bmatrix}$ and $L2 = \begin{bmatrix} 16 & 10 \\ 18 & 10 \\ 19 & 10 \end{bmatrix}$

The vector *Chosen_road* shows that the metric provides a mixed and alternating variation in the chosen paths. Figure 6 shows the variation of the remaining energy in nodes 5, 9 and 11.

The figure shows that when one node responds, the others remain dormant confirming that the three nodes do not belong to the same road. We also note that a step along the beginning of the simulation appeared during the study of the evolution of the remaining energy in node 11 which means that the way in which this node is involved is not a very desirable in terms of energy consumption. Thus, we can call this path the backup route because its use delays the death of nodes 5, 9 and their companions. We note that the simulation is stopped after the 23^{rd} data transmission. All these measures with their entry time are stored in the data acquisition card connected to the computer in the control room. Then the supervisor can collect the change in volume over time as shown in figure7.

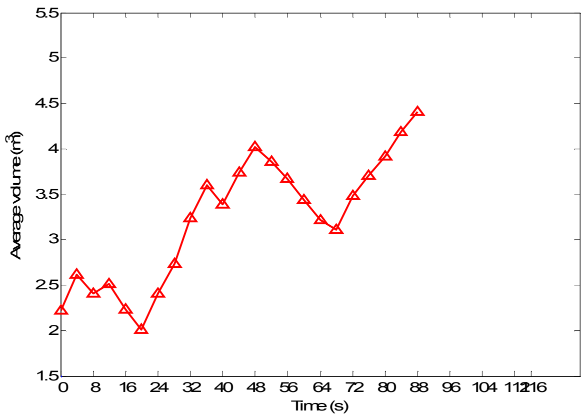

Fig. 7. The evolution of the average volume in the tank of propane.

These values are the results of averaging the different volumes detected at each interval of time by alive and healthy nodes. The analysis of these two factors can explain the cause of the sudden shutdown of our program. The study of the first factors shows that all detectors, identities [16 17 18 19 20 21], participate in the mission of data transfer to the sink node till the 22^{nd} data transmission. However, there is a lack in sensor nodes, identities [17 20 21], since the 23^{rd} iteration.

The study of the second factor shows that absence of some sensor nodes is temporary. This is explained by the failure of the node by detecting a measure that does not belong to the tolerance interval. In our example the identity of sensor nodes are represented in the following healthy vector:

$$Safes\_Knots = \begin{bmatrix} 16 & 17 & 18 & 19 & 20 & 21 \\ 16 & 17 & 19 & 20 & 21 & 0 \\ 16 & 18 & 19 & 20 & 21 & 0 \\ 18 & 19 & 20 & 21 & 0 & 0 \\ 16 & 17 & 18 & 19 & 20 & 21 \\ 16 & 18 & 19 & 20 & 21 & 0 \\ 16 & 18 & 19 & 20 & 21 & 0 \\ 16 & 17 & 18 & 19 & 20 & 21 \\ 16 & 17 & 18 & 19 & 20 & 21 \\ 16 & 19 & 0 & 0 & 0 & 0 \\ 16 & 17 & 18 & 20 & 21 & 0 \\ 17 & 18 & 19 & 20 & 21 & 0 \\ 17 & 18 & 19 & 21 & 0 & 0 \\ 16 & 17 & 18 & 19 & 20 & 21 \\ \vdots & & & & & \\ 16 & 17 & 18 & 19 & 20 & 21 \\ 16 & 17 & 18 & 20 & 0 & 0 \\ 16 & 17 & 18 & 19 & 20 & 21 \\ 16 & 18 & 19 & 0 & 0 & 0 \end{bmatrix}$$

A study of energy within two sensor nodes identity 16 and 20 was performed. The evolution of energy is represented in figure 8.

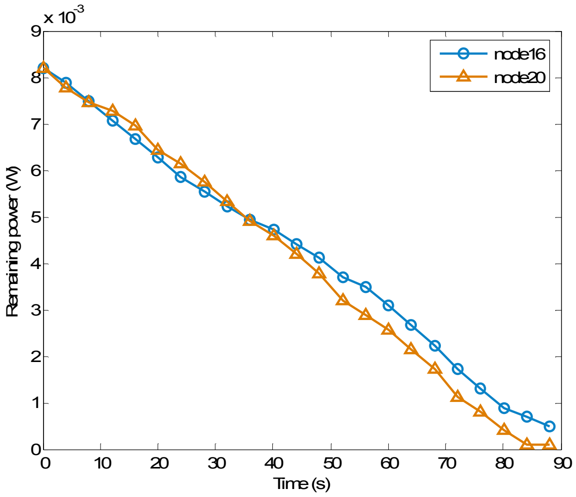

Fig. 8. Energy development in the two sensor nodes.

From this figure we can see that the energy consumption is variable over time. At the beginning, node 16 consumes more energy than node 20 till 36.05s. After this moment the energy remaining in the battery of node 16 becomes higher than that in node 20. This condition causes the death of node20 before node 16. The instant of battery depletion is specific for each node despite the equidistance between the sensor nodes and the sink node. Hence, energy equations depend not only on time but also on the number of backoff test transmission. These two variables evolve according to both Figures 9 and 10 above.

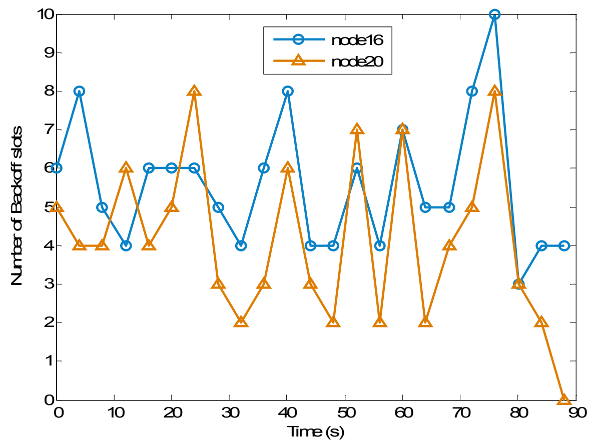

Fig. 9. Evolution of the number of backoff slots in both sensor nodes.

This figure shows that the points indicated on the curves are no longer similar which validates our program in estimating suitable backoff periods.

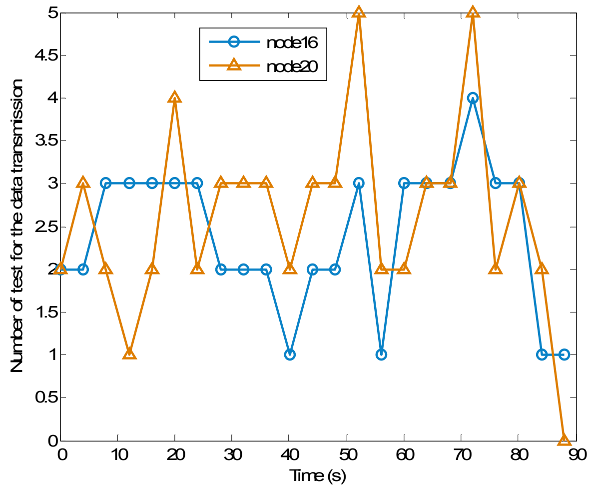

Fig. 10. Evolution in the number of tests to transmit the detected data by the various sensors.

There is also a good agreement between figure 8 and figure 9. Indeed a transmission failure usually leads to a new backoff period. Thus the rise in the backoff time is caused by the increase in the number of transmissions. To prove the death of nodes 17, 20 and 21, we will complete the sum of the backoff periods as well as the number of total transmissions made by each sensor node from the first detected value to the 22^{nd} captured measure. The result is represented by the two histograms below.

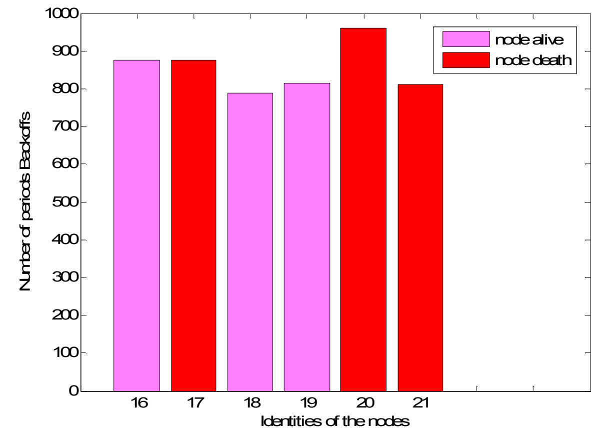

Fig. 11. The sum of the backoff periods executed by each sensor node till the 22nd iteration.

This figure shows that node 20 waits for a longer backoff period than other sensors which can justify the fast depletion of the battery. However, after the 22nd iteration node16 remains alive whereas node 17disappears despite the equality between the backoff periods used by both nodes. To find another argument to explain the node death we will study the number of transmissions made by each node.

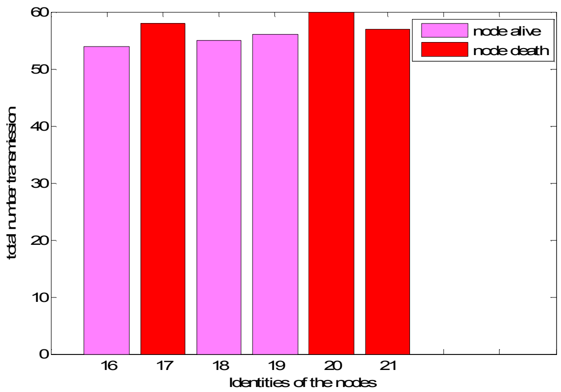

Fig. 12. The number of transmission test made by each sensor node till the 22nd data transmission.

The comparison between the total number of transmissions for each node shows that the higher the level the higher energy consumption is. Then the moment of node death is linked not only to the number of backoffs but also the number of tests performed by the sensor node to transmit the data to the receiver.

VIII. CONCLUSION

The control of the level of propane in a vessel is established during the implementation of an approach that is intended to direct the data to the base station. The operation of the algorithm CSMA / CA Slotted represents a challenge to ensure the arrival of the information to the sink node, taking into account the phenomenon of collision. This study has proven the capacity of the theory of treatment in discovering the failing sensors and calculating the average value to be transmitted to the base station while following the algorithm of intelligent routing. The latter is based on the mixed metric which gives the same value to the two criteria: energy consumption and elongation of the life time. All the techniques used in the approach we proposed led to a satisfactory supervision of fluid level.

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