Enhanced MR-LEACH Clustering Protocol in Wireless Sensor Networks based on Simulated Annealing

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Abstract—**The problem of energy consumption has become a very important axis of research for wireless sensor networks; energy saving must be ensured to keep the network working as maximum as possible, taking in consideration the packets loss and routing management. In this paper we present a routing protocol for WSNs based on simulated annealing metaheuristics (SA) and the MR-LEACH protocol. In this hybridization, we set the temperature parameter in SA as the residual energy of member sensors inside each cluster. The selection of cluster heads is based on the highest residual energy inside a cluster after applying the SA metaheuristics. Experimental results have shown the high performance of our proposed protocol compared to MR-LEACH especially in term of lifetime and energy consumption.**

Keywords: ***WSNs; energy consumption; MR-LEACH; Simulated Annealing; clustering***

I. INTRODUCTION

The technological advances realized in the fields of microelectronics and wireless communication have made it possible to design and manufacture miniaturized, low in cost and power, autonomous, reliable components such as sensors devices. Indeed, deployed over a large geographical area forming a network of wireless sensors in order to monitor commercial and industrial domains, civil and military environments, healthcare, security and emergency surveillance; to collect information on well-defined events, and to route them to a particular processing node, called base station (BS). The collected information are used to build a global vision of the area covered to make decisions [1].

Working on wireless sensor networks (WSNs) field has become one of the most investigated research domain during the last years. The design goals and applications related to the WSNs are currently considered in many recent research works starting from sensors deployment, connectivity management, coverage monitoring, localization preserving, energy economy, to building routing protocols [2].

However, the control of the energy consumption by the sensor networks and the maximization of their lifetime remain the most fundamental problems because the sensors are of small chap, a low capacity of storage, computing, and limited power with non-refilling ability. So for a sensor network to remain autonomous for a long time (a few months or years) and so have a maximum longevity, energy consumption must be taken into account at all aspects of sensor networks [2].

Our purpose in this paper is to introduce a new efficient routing protocol to WSNs field that limits high energy consumption and enhance topology of the network through a reliable clustering mechanism and an efficient search technique.

The rest of this paper is organized as follow. Section two provides a general introduction to wireless sensor networks, present its main characteristic. Section three presents the MR-LEACH clustering protocol and its phases. Then, the metaheuristic concept of the simulated annealing is presented in Section four. In Section five, we explain the principle of our proposed protocol that is based on simulated annealing metaheuristics and MR-LEACH. We discuss and analyze simulation results in Section six through metrics like protocol's lifetime, live nodes, number of clusters formed in the network, sent data to cluster heads as to the base station, residual energy, control packets, and the first dead node. Section seven is the conclusion.

II. WIRELESS SENSOR NETWORKS AND MULTIHOP CLUSTERING PROTOCOLS

A. *Sensor node*

Architecture of node focuses to reduce cost, increase flexibility, provide fault-tolerance, improve development process and conserve energy. The sensor node consists of sensing unit, processing unit (MCU-micro controller unit), storage unit, communication unit, and power supply as shown in Figure 1.

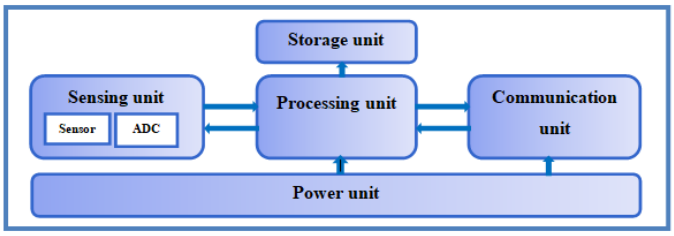

Figure 1. Sensor node structure [1].

- The Power unit: composed of power battery and DC-DC which is responsible for giving energy to the node. Battery cannot be replaced every time, so proper and efficient utilization of power must be necessary [2].
- The Communication unit: (transceiver) provide communication channel which may use radio, laser or optical and infrared [3].
- The Processing unit: which has memory (RAM), microcontroller, operating system and timer which are responsible for storing, processing and executing the events respectively [3].
- The Sensing unit: composed of collection of sensor which produces the electric signal by sensing physical environment and analog to digital converter (ADC) which transforms the signal [3].

The Storage/ memory unit: storage in the form of random access and read-only memory includes both program memory (from which instructions are executed by the processor), and data memory (for storing raw and processed sensor measurements and other local information). The quantities of memory and storage on board a WSN device are often limited primarily by economic considerations, and are also likely to improve over time [2].

B. *Wireless sensor Networks*

A wireless sensor network (WSN) is an infrastructure-less and self-organized network (Figure 2). It is composed of a group of sensor nodes, which communicate by electromagnetic waves. Each sensor node acts as both a sensor and a wireless router. The fundamental functions of WSNs are sensing, data gathering, processing information on monitored objects and transferring the information to the base station [4].

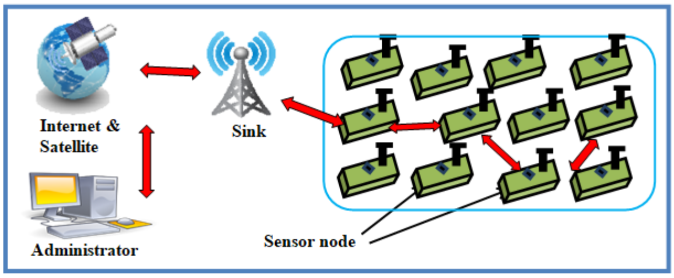

Figure 2. Wireless sensor network structure[1].

The major characteristics used to evaluate the performance of WSN are [5]:

- Fault tolerance
- Mobility of nodes
- Dynamic network topology
- Communication failures
- Heterogeneity of nodes
- Scalability
- Independency
- Programmability

C. *Challenges of WSNs*

Wireless sensor networks have tremendous potential because they will expand ability to monitor and interact remotely with the physical world. Sensors have the ability to collect vast amounts of unknown data. WSNs to become truly ubiquitous, a number of challenges and obstacles must be overcome [6][7][8].

- Energy
- Limited Memory and Storage Space
- Deployment
- Fault Tolerance
- Design Constraints
- Limited bandwidth
- Synchronization
- Privacy and security

WSNs were originally motivated by military applications, which range from large-scale acoustic surveillance systems for ocean surveillance to small networks of unattended ground sensors for ground target detection. However, the availability of low- cost sensors and wireless communication has promised the development of a wide range of applications in both civilian and military fields. This section introduces a few examples of sensor network applications.

D. *Applications of WSNs.*

Over the last years, WSNs have been used in different domains that require continuous monitoring [9]:

- Habitat monitoring
- Air or water quality monitoring
- Hazard monitoring
- Disaster monitoring
- Battlefield monitoring:
- Medical monitoring
- Smart home
- Remote metering
- Security and surveillance applications

III. MULTIHOP ROUTING LEACH (MR-LEACH) PROTOCOL

In MR-LEACH, there are three steps that compose the protocol [10]. First, clusters are formed, then, the hierarchical structure of clusters is defined, and finally the phase of sending data in hierarchal manner to the base station.

A. Clusters formation

In order to form clusters in the network, each node broadcasts the HELLO message to its neighboring nodes within its transmission radius [10]. Once the cluster is formed, sensor node will save the node ID of CH and all other data will be discarded. If certain node has the largest residual energy among all its neighboring nodes, it elects itself as a CH. Afterwards, it broadcasts a header message (HEAD_MSG). When no CH node receives multiple HEAD_MSG, a node will select the CH whose HEAD_MSG has the highest Received Signal Strength. Once, a node selects the CH it changes the status of CH node to "Cluster Head" and similarly CH will change the status of all its member nodes status to "Members".

B. Cluster hierarchy formation

When clusters are formed, the second phase starts to determine the hierarchical relation between CHs to reach the BS as shown in Figure 3 [10]: The BS broadcasts a message with its ID over the common control channel to all CHs. The broadcasted signal should be of low strength to reach closer CHs only. CHs near to BS acknowledge the reception and form the first hierarchical layer; these CHs are single hop away from BS. The BS broadcasts a control packet of discovered CHs IDs with higher transmission range to find new CHs and build a hierarchical links with the old CHs, and thus, building the second layer CHs. The process is repeated until no new CH is discovered.

C. Scheduling

Time Division Multiple Access (TDMA) is the preferred scheduling scheme in sensor networks because it saves lot of energy compared to contemporary medium access tetchiness for wireless networks. Upper level cluster heads will allocate longer time slots to their member low level CHs because they have more data to send compared to simple members [10].

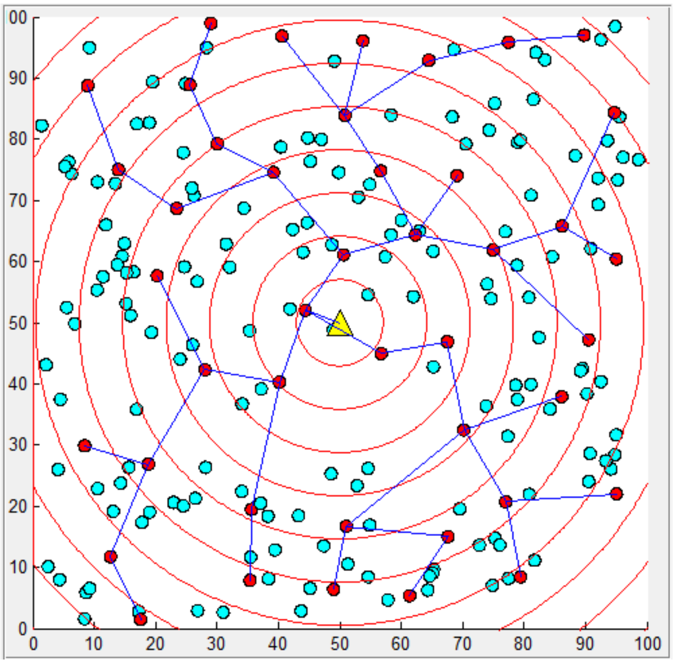

Figure 3. Hierarchical structure of WSNs using the MR-LEACH protocol.

IV. SIMULATED ANNEALING APPROACH

Creating and introducing new routing protocol to WSNs area is in a permanent and progressive operation. Therefore, Routing protocols compete each other in term of which one is the most efficient to the network cost and lifetime. In this section, we first preview in details the metaheuristic Simulated Annealing algorithm, its main basics, and then we present our proposed protocol.

The name of simulated annealing origins from the simulation of annealing process of heated solids. In condensed matter physics, annealing denotes a physical process in which a solid in a heat bath is heated up by increasing the temperature of the heat bath to a maximum value at which all particles of the solid randomly arrange themselves in the liquid phase, followed by cooling through slowly lowering the temperature of the heat bath. In this way, all particles arrange themselves in the low energy ground state of a corresponding lattice.

In solving combinatorial optimization problems, we make an analogy to the aforementioned process. The basic idea is that by allowing the search process to proceed in an unfavorable direction occasionally, we might be able to escape the trap of local optima and reach the global optima [11].

A. Simulated Annealing Algorithm

Simulated annealing is a global optimization algorithm modeled after the natural process of crystallization, where a metal is melted and then allowed to cool slowly. If it is cooled too fast, the metal does not reach its lowest possible energy. The metal must be allowed to cool slowly in order to reach its lowest energy state. Similarly, with simulated annealing of a set of data containing a finite number of points, the points are heated (randomized) and then allowed to cool. In cooling, a random change is made to the system, usually either a random exchange or a reversal of a random section of points. The change is accepted or rejected based upon the Metropolis criteria [12] (Metropolis: simulate behavior of a set of atoms in thermal equilibrium, it models how a thermodynamic system moves from one state to another state in which the energy is being minimized [13]). If the change results in a lower amount of energy, then it is accepted unconditionally. However, to prevent the system from becoming stuck in one of the local minima, uphill moves (ones with a positive change in energy) are accepted according to the Boltzmann probability distribution of $P(E) = \exp(-\delta E/kT)$ where k is Boltzmann's constant, T is the temperature, and δE is the change in energy. Initially, it begins at a number that is chosen by the user. The temperature is then reduced in coordination with a temperature schedule. If the temperature is too large, the program accepts uphill climbs too readily, and will potentially move away from the global minimum. If the temperature is too small, the program is likely to get stuck in a local minimum [12].

Algorithm: Simulated Annealing [14].

Procedure Simulated Annealing()

Input: cooling schedule

S=S_0 ; /*S = Initial Solution*/

T=T_0 ; /*Initial Temperature*/

g(); /*Function of decreasing Temperature*/

Repeat

Repeat/*fix Temperature*/

Generate a random neighbor S';

$\Delta E = f(S') - f(S)$

If $\Delta E \leq 0$ $S = S'$

Else accept S' with a probability $\exp(-\Delta E/kT)$

Until Equilibrium condition is reached

T=g(T);

Until Stopping criteria satisfied

Output: Best solution found

V. OUR PROPOSED PROTOCOL

In order to perform initial topology of the network, our proposed protocol basis on the MR-LEACH clustering methodology for the first round, and for the next rounds SA-MR-LEACH clustering method is used.

There are three main phases in our proposed protocol: the cluster formation phase, the multihop phase and the steady state phase.

1) Cluster formation phase

In our proposed protocol the clusters are formed depending on MR-LEACH topology for the first round in order to consume lower energy. As shown in Figure 4, each regular node send hello message to nodes within its radius transmission, and elect them as neighboring nodes. Then, each node changes its state to be CH if it has the highest energy among its neighbors. Then, the neighbor nodes send reply messages to the nearest CH to join its cluster.

The next rounds of re-clustering is performed after a certain period; where each CH initialize a threshold T and a parameter α that allows to reduce the threshold, sends the threshold to its cluster members (Figure 5), then request them for their remain energy by sending an energy request message (Energy-Req-Mssg), each sensor member, after receiving T and Energy-Req-Mssg compares its own residual energy to the threshold T, with no exception even the CH itself checks its battery level so as to optimize re-clustering period and thus clustering stay the same for certain period, if the node energy is greater than or equal to the threshold, it sends its energy to its CH, and this last one add it to a list of best K candidates nodes to become new CH, otherwise it remains a regular node. The benefit is in reducing transmission cost, such as only nodes whose satisfy the threshold send their energy to CH, and so are able to join the list. The CH receives energies packets and add nodes one by one to the list, in order to reach balance in network, a good distribution of cluster is provided which enhance the irregular number of clusters in each round; the CH checks the length of the list, if there is just one node that passed the criteria, then the CH is obliged to reduce the threshold and re-broadcasts it to members. Once the list is formed, the CH applies the Simulated Annealing algorithm to choose the next CH; where a random number $r \in [0,1]$ and the probability $P = \exp(-\Delta E/T)$ decides if a node i with energy E_i or a node j with energy E_j is the new CH, where $\Delta E = E_i - E_j$ and T is the temperature which defines total residual energy. The new CH broadcasts CH-Announcement, and if there is an isolated nodes in neighbors clusters, they can join this cluster by sending Join-Req-Mssg to that CH, than it creates TDMA schedule and broadcast it, this prohibits to form a lot of clusters of only one or two members in the network.

2) Multihop phase

In this phase data routes to the BS are built using inter-cluster communications. We form hierarchical clusters using MR-LEACH where, the BS broadcasts its ID with a low strength to reach only closer CHs, which form the first layer and one single hop from the BS. To build the second layer, the BS broadcasts discovered CHs IDs with higher transmission strength than the previous one to find new CHs and build hierarchical links with the old ones; and the process is repeated until no new CH is discovered.

3) Steady state phase

During this phase, the process of transferring aggregated data of sensor nodes in CHs to the BS is done. Based on a time slot allocated in TDMA schedule, member nodes in each cluster transmit their sensed data to their specified CHs, which forward it to the BS through relay nodes (CHs), and they turn off until next slot of their allocated time in TDMA schedule. The general flowchart of our proposed protocol is in Figure 6.

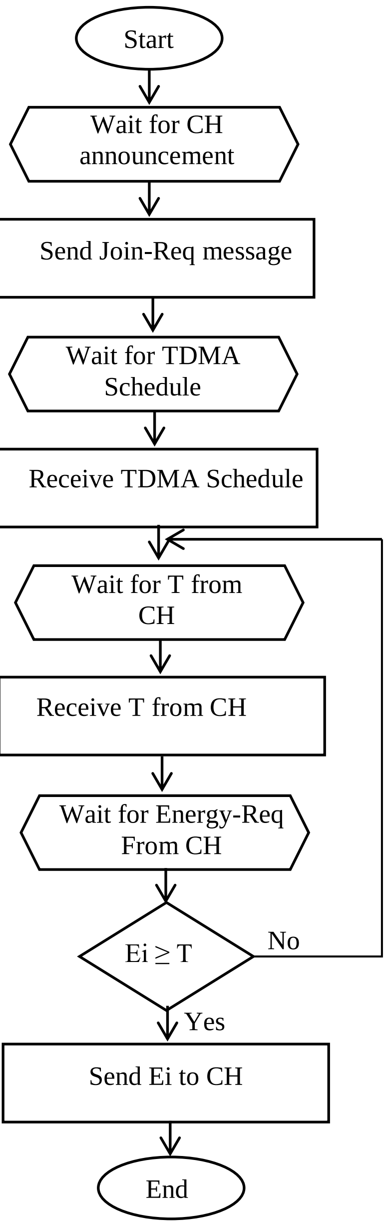

Figure 4. Regular node behavior flowchart during SA-MR-LEACH rounds.

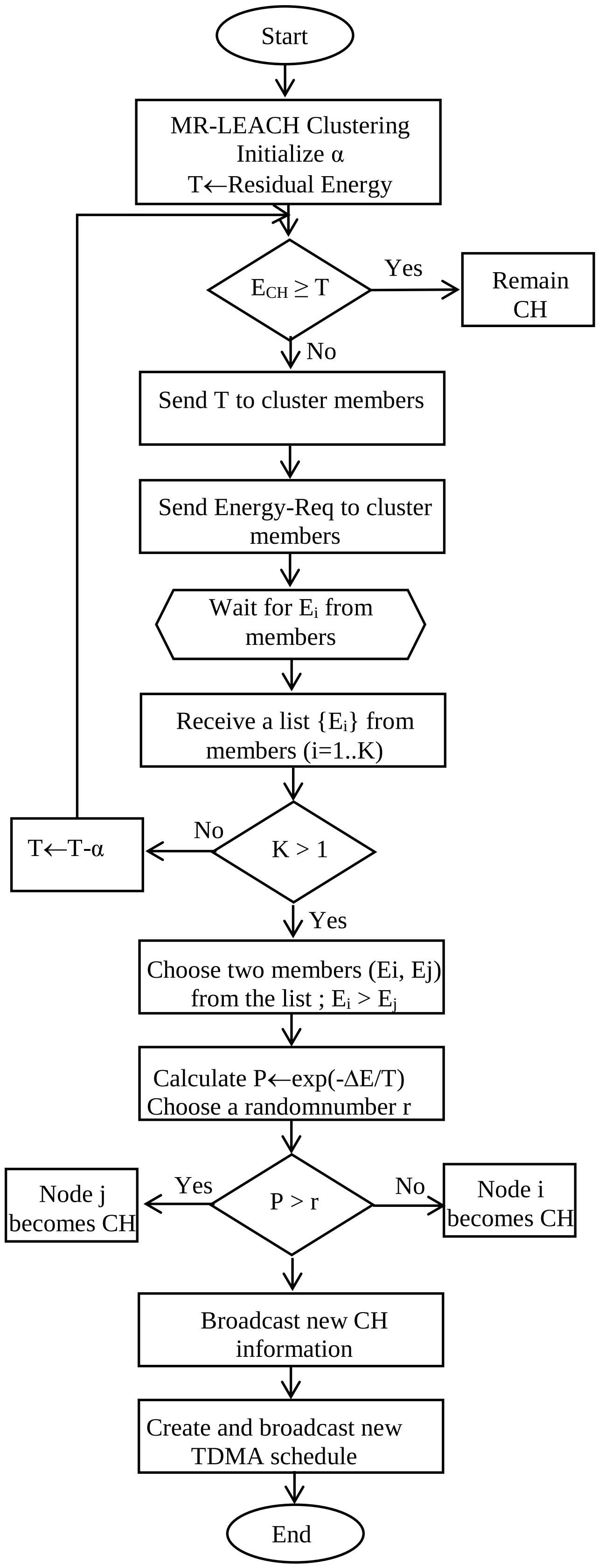

Figure 5. CH behavior flowchart during SA-MR-LEACH rounds.

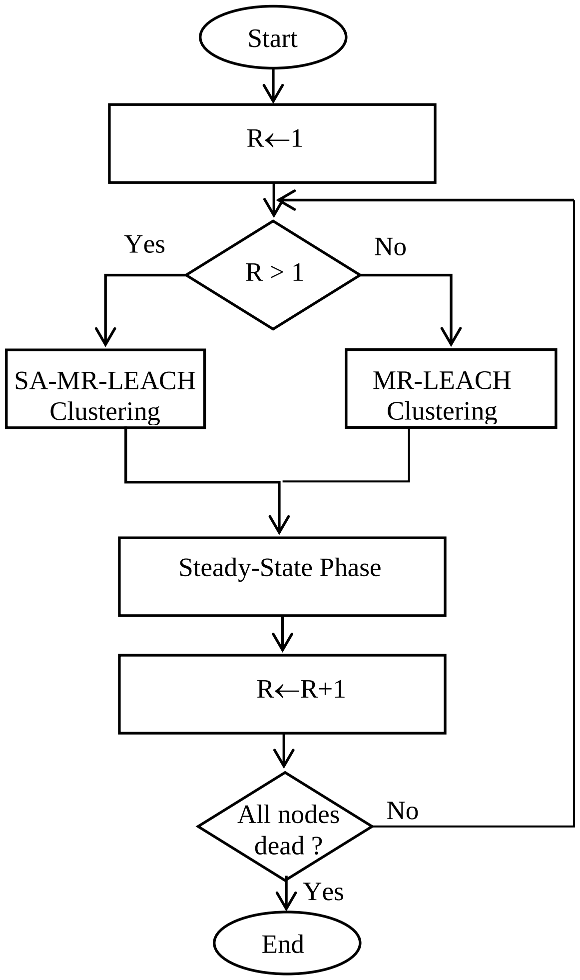

Figure 6. General flowchart of SA-MR-LEACH protocol.

VI. SIMULATION, RESULTS AND ANALYSIS

A. Hardware characteristics for MATLAB environment

During all experiments of simulation, we used the following hardware characteristics.

TABLE I. HARDWARE CHARACTERISTICS

Processor	Intel (R) Core(TM) i3-2330M @ 2.20GHz, 2300MHz
Memory (RAM)	4.00Go
Operating system	Microsoft Windows 7 Professionnal 64-bit

B. Network model

The nodes are distributed randomly in a 2-dimensional space. The sensor nodes are fixed and homogeneous in processing and communication capabilities. The initial energy is uniform for all the nodes and it is impossible to recharge them.

C. Energy dissipation model

We use a simple model of radio control. In this model, a radio dissipates E_{elec} = 50 nJ/bit to run the transmitter or receiver and E_{mp} = 0.0013 pJ/bit/m2 for the transmitter amplifier. When the distance between two nodes or the base station is greater than the distance d_0, the multipath fading channel model (ε_{mp}) is used, and in the lower case, the free space model channel (ε_{fs}) is used. Radios have the power of control and can spend the minimum energy needed to reach intended recipients. The radios can be turned off (sleep mode) to avoid receiving unintended transmissions. The equations used to calculate the transmission costs and the reception costs for a message of L bits and a distance d are given below:

To transmit a message of L bits over a distance of d meters, the transmitter consumes:

$$E_{TX}(L,d) = \begin{cases} L * E_{elec}(L,d) + L * \varepsilon_{fs} * d^2, d < d_0 \\ L * E_{elec}(L,d) + L * \varepsilon_{mp} * d^4, d \geq d_0 \end{cases}$$

- E_{elec} : Sufficient energy to transmit or receive a single bit.
- ε_{fs} : Amplification factor corresponds to the "free space channel".
- ε_{mp} : Amplification factor corresponds to the "multipath fading channel".
- E_{da} : The data aggregation energy.
- L : The size of a message.
- d_0 : The limiting distance for which the amplification factors change in value.
- d : The distance between the transmitter and the receiver.

To receive an L-bit message, the receiver consumes:

$$E_{TX}(L) = L * E_{elec}$$

In order to examine efficiency of each of the protocols MR-LEACH and SA-MR-LEACH, and in order to evaluate the performance of our protocol we provide a scenario with four cases that performs a great enhancement to our protocol functionality in different metrics of simulation. The scenario presents cases of choice of sensor nodes E_i and E_j to calculate energy diffrence ΔE of Simulated Annealing algorithm. The cases define the choice of the maximum or the minimum in term of energy level, or when it is randomly chosen.

- Case 1: the node E_i has the maximum energy and E_j has the minimum energy.
- Case 2: the node E_i is randomly chosen and E_j has the minimum energy.
- Case 3: E_i has the maximum energy and E_j is randomly chosen.
- Case 4: both of E_i and E_j are randomly chosen.

TABLE II. SIMULATION PARAMETERS

Parameter	**Value**
Protocols	MR-LEACH, SA-MR-LEACH
Number of nodes	200
Location of BS	(50, 50)
Simulation area	100m X 100m
Node Deployment	Random
Packet size	500 Bytes
Initial energy	0.1J
E_{elec}	50nJ/bit
ε_{fs}	10pJ/bit/m^2
E_{da}	5pJ/bit/sig
P	0.1
Coverage Radius	50

D. Results

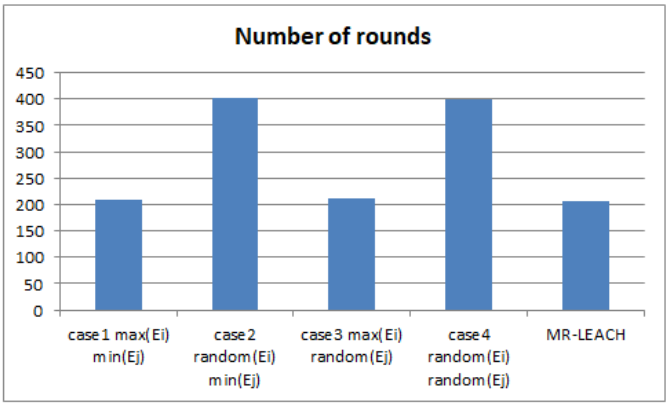

Figure 7. Comparison of lifetime of SA-MR-LEACH, MR-LEACH.

Figure 7 presents the lifetime of each protocol during simulation. Results show clearly that SA-MR-LEACH endures more than the other protocol. This is due to the best clustering which stays the same until CHs battery falls under the threshold T. Moreover, it provides an equal selection to CHs with randomness factor in the Simulated Annealing algorithm, and takes consideration to residual energy in sensors before the selection operation. In MR-LEACH, the clustering is in each round where each node broadcast its remain energy to neighbors in order to select CHs.

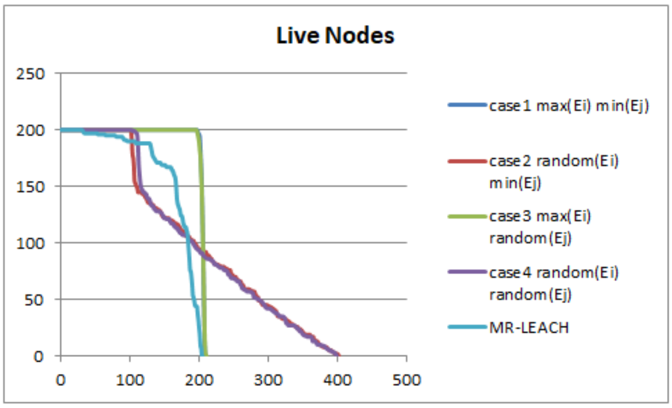

Figure 8. Live nodes versus Number of rounds.

Figure 8 illustrates the number of live nodes of the two protocols. We observed that case 1 and case 3 which represent maximum energy nodes to be CHs, are equal and stables until round 200 where number of nodes decrease rapidly, because it always chooses the best sensors even if they are isolated in their clusters, whereas cases 2 and 4 that number decreases slowly in a linear manner, because it chooses them randomly, so it gives a chance to all sensors to become CHs at least once.

MR-LEACH loses its nodes early due to the clustering mechanism that happen twice of times, the first one is for cluster formation at lowest level, and the second one is at different level of hierarchical layers.

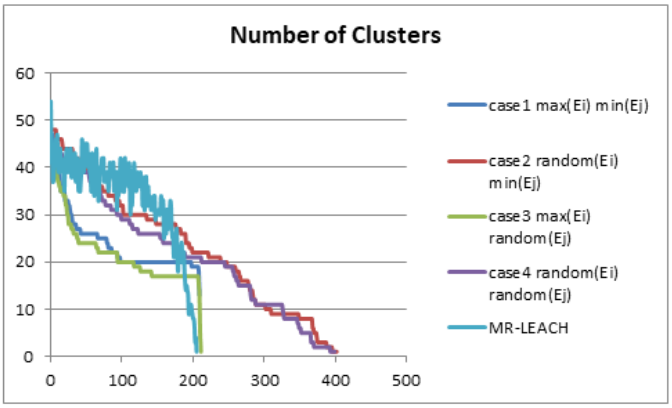

Figure 9. Number of clusters versus number of rounds.

Figure 9 presents the number of clusters over number of rounds for the two protocols. The early diminution of cases 1 and 3 of SA-MR-LEACH compared to the other cases refers to decrease of the number of live nodes, and it stays stable between rounds 100 and 200 because the number of nodes stays the same during these rounds. In cases 2 and 4, the number of cluster heads decreases as well as the live nodes during the same rounds. The SA-MR-LEACH protocol optimizes the number of clusters because after the broadcast of CH announcement, closer nodes belonging to other clusters can join a new cluster if that CH is closer compared to the initial CH.

MR-LEACH clusters decrease corresponding to the decreasing of live nodes based on the selection method of CHs. However, our protocol shows a good enhancement by selecting CHs using a random way according to the probability acceptance criteria of Simulated Annealing, as it checks battery level using a threshold T.

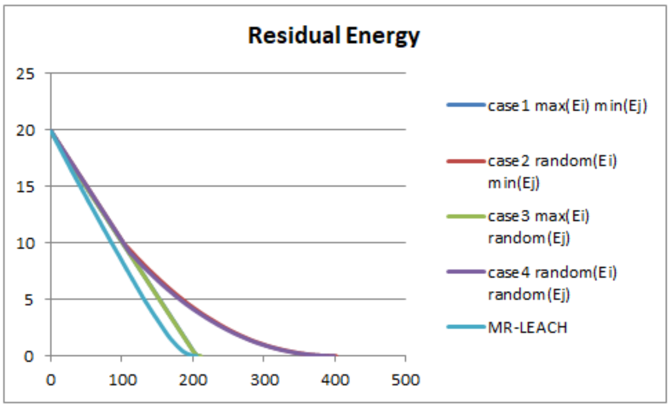

Figure 10. Residual energy versus number of rounds.

Figure 10 presents the residual energy in the network versus the number of rounds for the two protocols. All protocols deacrease in energy with number of rounds, but SA-MR-LEACH saves the network energy until round 402, because it keeps the same cluster members for certain period of time and a new CH are selected only if energy of current ones are less then threshold T. On the other hand, reclustering in MR-LEACH is done in every round, so more energy is consumed. Moreover, the number of cluster varies between rounds while in SA-MR-LEACH clusters stay static for certain rounds. In fact, the number of live nodes in rounds between 0 and 130 remained fixed.

So, results of cases 2 and 4 are better than those of cases 1 and 3 because the special choice of high energy nodes rather than their position waste a lot of energy.

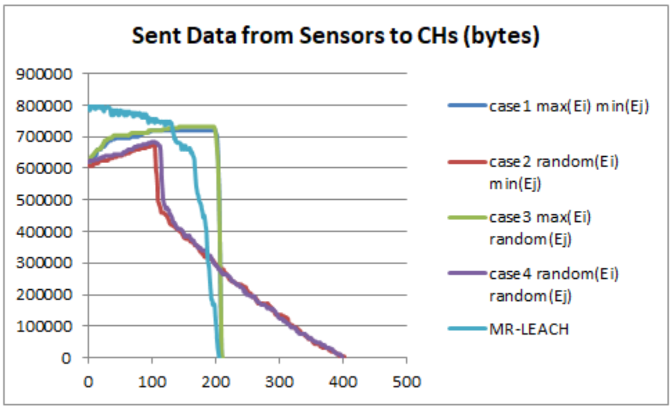

Figure 11. Sent data from sensors to CH versus number of rounds.

Figure 11 illustrates number of sent data from sensors toward their CHs. In rounds between 0 and 100, in all cases of SA-MR-LEACH and before losing nodes, the amount of sent data from sensors to CHs increases while all nodes stayed alive because in each clustering round sensors send their remaining energy to their CHs. Then, when some nodes run out of energy, the amount of sent data decreases and the topology of the network is changed. Therefore, the balance of energy in the network between nodes becomes uneven due to many reasons like the distance between CHs and their members. Besides, the threshold decreases corresponding to the battery level in each cluster. Then, a rebroadcast is performed where sensor members compare it and send their remaining energy to CHs. In MR-LEACH, the amount of sent data from sensors to CHs decreases because the number of nodes decreases referring to its clustering mechanism.

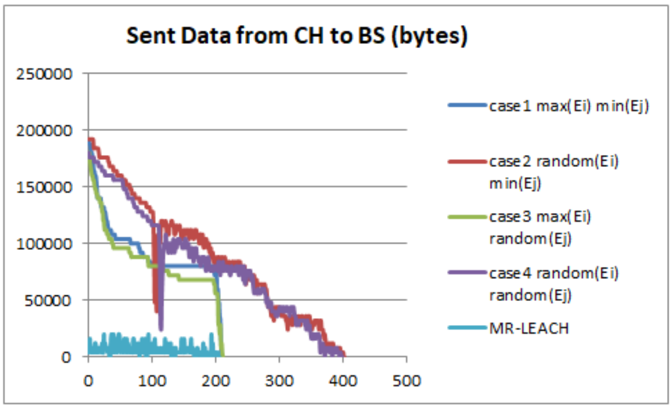

Figure 12. Sent data from CHs to BS versus number of rounds.

Figure 12 presents number of sent data from CHs to the BS. The amount of data is lower in MR-LEACH and SA-MR-LEACH because both of the two protocols use multi-hops CHs for data routing, thus the number of communication points with the BS is lower.

Cases 1 and 3 are experimentally equal and decrease and remain stable between 100 and 200 because the number of clusters decreases during the same interval of rounds ; as we observed the same decrease manner for cases 2 and 4.

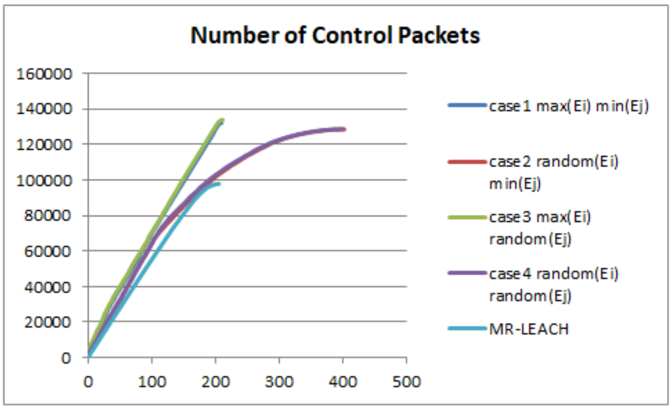

Figure 13. Number of control packets versus number of rounds.

Figure 13 illustrates the number of control packets versus number of rounds for each protocol. In all cases of the scenario, Number of control packet in all protocols increase equally until around round 120 where cases 1 and 3 continue increasing directly until round 200 because in this period all nodes were alive, while in MR-LEACH and cases 2 and 4 increase equally until round 200. However, control packets of cases 2 and 4 are a little higher than MR-LEACH due to the request and receiving of residual energy in sensor members. SA-MR-LEACH shows the highest amount of control packets. These control packets are due to communication with closer nodes, which means just between CHs and their members as a request of sending their remained energy in order to select new CHs and receive of threshold by cluster members that occurs only after certain period. Another reason is that CH selection at hierarchical level makes SA-MR-LEACH suffer from another consequent control overhead, since it may needs several iterations in the process of CH discovering at this level. This overhead also exists in MR-LEACH but clustering at low level is different in the two protocols.

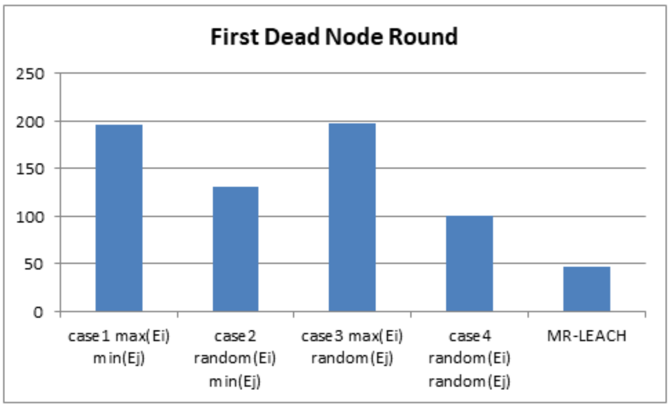

Figure 14. The first dead node though simulation rounds.

Figure 14 presents the first dead node during simulation rounds. Cases 1 and 3 of SA-MR-LEACH loses their first node until round 185 due to the choice of maximum nodes in the level of energy that extends the period before losing nodes. Whereas in cases 2 and 4 the network loses its first node just in round 110 because nodes are chosen randomly where the worst case is when the battery level is too low and thus it loses nodes early. MR-LEACH loses its first node early than SA-MR-LEACH in round 43, because in each round each node broadcast its residual energy in order to select new CHs and then forming clusters.

E. Analysis

After simulation of the two protocols, we observed that the case 2 which presents SA-MR-LEACH (Random, Min) is the best case, since it has the maximum number of rounds 402. We conclude that the random choice of CHs can improve lifetime of routing protocols in SA-MR-LEACH clustering, but only with some limitations to randomness using some conditions such as the battery level.

Compared to the other protocols SA-MR-LEACH leads to a lot of control packets, because with rounds energy of sensors decreases, and in certain rounds it became under the threshold. The advantage of our protocol is to decrease the threshold so as to nodes energy satisfy the threshold and thus allowing formation of new clusters. After the decreasing operation, the threshold must be re-broadcasted by CHs in order to select new CHs, after that the next step is the process of requesting and receiving energy from members and which leads to more control packets. However SA-MR-LEACH shows high performance in both of network lifetime, number of formed clusters in the network, data delivery to CHs as to the BS, residual energy, and the first dead node. This was due to the method of clustering which send to the condition of residual energy in sensors to be elected as CHs and also in CHs to maintain the connectivity of the network the maximum as possible. Moreover, the multi-hop factor involves energy saving using shortest paths to the base station.

VII. CONCLUSION

The problem of energy saving will remain for several years a central concern in wireless sensor networks research area. It bases its strategy on the use of hardware and software to minimize the energy expenditure needed to make the network work as long as possible. These are precisely the expenses to feed the internal components of a node and the expenses required by the communication protocols.

In this paper, we provided an analysis to demonstrate the well-design and effectiveness of our proposed protocol in energy consumption and management, as also network topology. In our study, different metrics have been used for comparison between protocols: lifetime, control packets, received data by CHs and the BS, live nodes, number of clusters formed in the network, residual energy, and the first dead node through the simulation rounds.

We applied many scenarios to evaluate and analyze performance of our protocol. Our simulation results showed that MR-LEACH leads the protocols in terms of control packets. However, SA-MR-LEACH showed the best performance in terms of all other metrics due to the efficient clustering manner and the reliable search technique.

REFERENCES

[1] Kirti, M., "Basic Concepts of Wireless Network", In: International Journal of Science and Research (IJSR), ISSN: 2319-7064, Vol.3, July 2014.

[2] Jun, Z., Abbas, J., "Wireless Sensor Networks: A Networking Perspective", In: Proceedings of the 2009 IEEE Conference on Wireless Communications & Networking Conference, The Institute of Electrical and Electronics Engineers Inc., pp. 2932–2937, September 2009.

[3] Ajay J., Richa, J., Swati, J., "Wireless Sensor Network (WSN): Architectural Design issues and Challenges", In: Proceedings of the 9th International Journal on Computer Science and Engineering (IJCSE), Vol. 02, pp. 3089-3094, November 2010.

[4] Liao, J., "Application of Simulated Annealing Algorithm to Wireless Sensor Networks", June 2006.

[5] Chiara, B, Andrea, C, Dardari, D, and Verdone, R., "An Overview on Wireless Sensor Networks Technology and Evolution", In: Sensors Journal, Vol. 9, ISSN: 1424-8220, pp.6869-6896, August 2009.

[6] Sharma, S., Bansal, R., and Bansal, S., "Issues and Challenges in Wireless Sensor Networks'', In: International Conference on Machine Intelligence Research and Advancement, 2013.

[7] Karthik, S., Ashok Kumar, A., "Challenges of Wireless Sensor Networks and Issues associated with Time Synchronization", In: Proceedings of the UGC Sponsored National Conference on Advanced Networking and Applications, March 2015.

[8] Akkaya, K., Younis, M., "A survey on routing protocols for wireless sensor networks", In: Elsevier Journal of Ad Hoc Networks, Vol. 3, pp.325-49, 2003.

[9] Zheng, J., Jamalipour, A., "Introduction to Wireless Sensor Networks", In: SENSAFETY: Sensor Networks For Public Safety, Australia: University of Sydney, July 2014.

[10] Omari, M., Hadj Fateh, W., "Hybrid Hierarchical Clustering Protocol in Wireless Sensor Networks based on Ant Colony Algorithm and MR-LEACH", In: Proceedings of the International Conference on Intelligent Information Processing, Security and Advanced Communication, 2015.

[11] Xiaocang, L., Yu-Chi, H., "Introduction to Simulated Annealing'', August 2003.

[12] Kitchener, D., "Simulated Annealing Techniques and Overview'', Florida State University, Tallahassee, USA.

[13] Olivier, W., "Simulated Annealing A Basic Introduction'', Massachusetts Institute of Technology, 2010.

[14] Talbi, A., "Methaheuristics from Design to Implementation", In: CNRS-INRIA, France: University of Lille, ISBN: 978-0-470-27858-1, John Wiley & Sons, Hoboken, New Jersey, 2009.