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Research paper

Wireless Sensor Network Energy Optimization in Smart Home Using LEACH Protocol: Comparative Study with CTP Routing Protocol

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Abstract

Advances in technology make it possible today to integrate, by low-cost, heterogeneous and wireless communicating multi-sensor objects. These intelligent sensors, also called wireless sensor networks (WSN), are used for monitoring and management in environments considered to be at risk or inaccessible such as smart homes. As a result, the sensor network efficiency is of major importance. Nevertheless, many constraints must be solved for wireless sensor networks like routing and energy management to extend the life of these networks. Thus, we suggest, in this paper, an optimization strategy based on the Leach protocol, under the OMNET ++ environment, in order to minimize the energy consumption in a WSN of a smart home. The simulation results show the effectiveness of the adopted strategy by comparing it to other algorithms particularly CTP protocol.

Keywords: *WSN; Smart Home; Routing Protocol; Energy Management; OMNET++.*

1. Introduction

Nowadays, a rapid revolution that has brought significant progress in the technological field of wireless communication and the electronic components miniaturization has emerged. Previously, the information routing collected by a sensor was achieved via a wired transmission medium that was cumbersome and expensive and its installation had to justify prospects of significant economic benefits. Now, each sensor node has a radio circuit for transmitting and receiving information via a wireless medium. As a result, several wired applications have converted into wireless considering the benefits. This evolution has allowed the sensor network emergences in hostile environments to which man does not always have access. This is why it's considered that once it is deployed, the sensor nodes are autonomous. Most of them have very limited resources in terms of computing capacity, memory space, transmission rate and energy. They operate at low voltage and their service life is the life of their batteries. These constraints have influenced many of the domain's research issues. Mainly, the network lifetime is a major concern given the often difficulty to access areas of long-term applications, such as monitoring applications (forest, ocean, volcano, etc.). It is often impossible to recharge or replace the batteries of the nodes after their exhaustion. There is, therefore, a problem of energy conservation which directly influences the network lifetime, especially if the application must work for a long time. The energy factor is therefore at the center of all the concerns about the sensors. The radio module is the most energy-hungry component in these networks where 70% of the sensor node energy is consumed by the data transmission and reception. In this context, reducing routing paths and accounting for residual energy in node batteries in a WSN can have a major impact on the network lifetime and energy consumption due to communication. Several experts who have worked on optimizing energy consumption in order to increase the sensor network lifetimes, have discussed and reviewed various energy coverage optimization protocols. These protocols are generally classified as clustering and distributed protocols. In addition, these protocols are classified according to the type of sensing model used, node location information, and the mechanism used to determine the neighboring node information. A hybrid approach was developed in [2]; it is the optimized QoS-based cluster with multipath routing protocol (OQoS-CMRP) for WSNs. This algorithm allows reducing the energy consumption in the well coverage area by applying the clustering algorithm based on Particle Swarm Optimization (PSO) to form clusters and solve the energy problem. The Single Sink-All Destination algorithm is used to find a near-optimal multi-hop communication path between the sink and the sensors to select the next hop neighbor nodes. The round-robin path selection algorithm is used for transferring data to sink. [3] It suggested a hybrid method based on ant colony optimization and particle swarm optimization on the basis of energy-efficient clustering and a tree-based routing protocol. Initially, the clusters are formed on the basis of the remaining energy, and then, the ACOPSO-based hybrid data aggregation will come in action to improve inter-cluster data aggregation further. Extensive analyses demonstrate that this proposed protocol significantly improves network lifetime over other techniques. A survey by [4] explores various search approaches and extensions to the problem which includes online routing, clustering approaches, and lifetime maximization on specially structured networks. We further consider the impact of having mobile and / or multiple skins and routing tolerant delays. Then, they conducted an analysis to examine multi-criteria optimization problems and define future research challenges in the field. An improved multi-objective weighted clustering algorithm (IMOWCA) was proposed by [5] using additional constraints to select cluster heads in WSN. IMOWCA aims to manage a WSN in certain critical circumstances where each sensor satisfies his own mission according to his location. In addition to fulfilling its mission, the sensor attempts to improve the communication quality with its neighboring nodes. This algorithm divides the network into different clusters and selects the best performing sensors on the basis of residual energy to communicate with the base station (BS). In this context, this paper aims at minimizing the energy consumption in a WSN via the LEACH routing protocol and consequently increasing the lifetime of the WSN installed in a smart home. Thus, the paper is structured as follows: The first section is reserved for the presentation of the wireless sensor network (architecture of the sensor node, typology of the network, etc ....). The energy optimization of the wireless sensor network as well as the routing protocol will be reserved in the second section. Then, the case study that represents the smart home will be presented and in the last section, simulations will be done in order to disassemble the efficiency of the chosen protocol and this with which we made the comparison.

2. Wireless Sensor Networks

Wireless Sensor Networks (WSN) are based on the collaborative effort of a large number of extremely small devices with very limited resources, called sensor nodes that operate in an autonomous way and ranging from a few tens of elements to several thousands to form a network without established infrastructure. Their positions are not necessarily predetermined. They can be randomly dispersed across a geographic area called the "capture field". A sensor node is able to monitor its environment and react when needed, by propagating the data collected to the Base Station called "sink", belonging to its coverage area via a multi-hop routing. This sink node then transmits this data over the Internet or satellite to the user's central computer to analyze this data and make decisions. The basic diagram of the wireless sensor networks is given in figure 1.

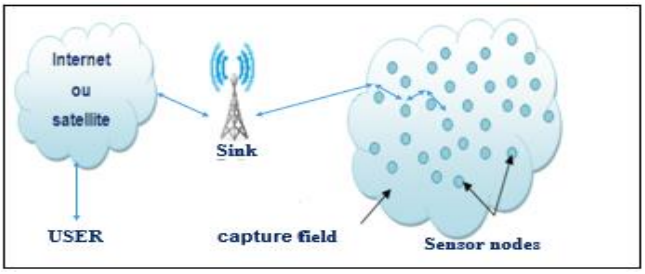

Fig.1. Global architecture of a Wireless Sensor Network.

2.1. Sensor node Architecture

The sensor nodes are designed as embedded systems equipped with processing and information communication means. They mainly integrate six basic units as shown in Figure 2: the capture unit, the processing unit, the transmission unit, the energy manager, the battery and the energy collector. These units are briefly defined in the following figure.

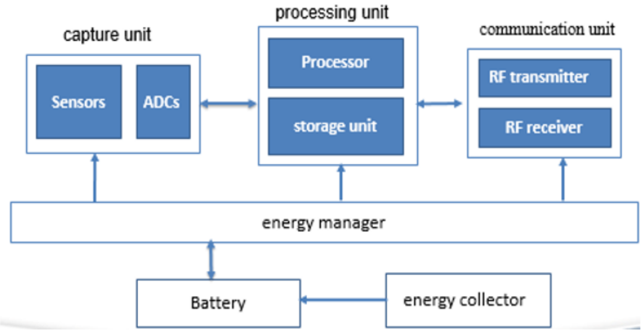

Fig 2. Sensor Node Architecture.

2.2. Architecture in Layers of Wireless Sensor Networks

Given the large number of features implemented in sensor networks, the architecture of these is particularly complex. The layered architecture in the WSNs as well as in the networks in general, and which is used by the Sink and all the other sensor nodes makes it possible to reduce this complexity by decomposing the processes which are implemented there. Such a division allows the network to process in parallel the functions assigned to the different layers. In this modeling, a layer corresponds to a set of functions or processes that are coherent with one another and ensures a precise overall function. It is clear that it is an architecture that implements the Open Systems Interconnection (OSI) network communication reference model with a reduction of layers because for sensor networks, the OSI model appears to be too complex. Indeed, very few applications need a division into seven layers, and in fact for sensor networks, 4 layers are sufficient.

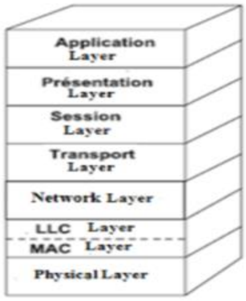

Fig 3. OSI model

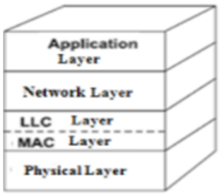

Fig 4. WSN layer model.

2.3. Information collection in WSNs

The information collection in the WSNs is either on demand or following an event.

2.3.1. Information collection on demand

When it is desired to have the status of the coverage area at a time T, the sink sends emissions to the whole area for the sensors to trace their last readings to the sink. The information is then routed through a multi-hop communication.

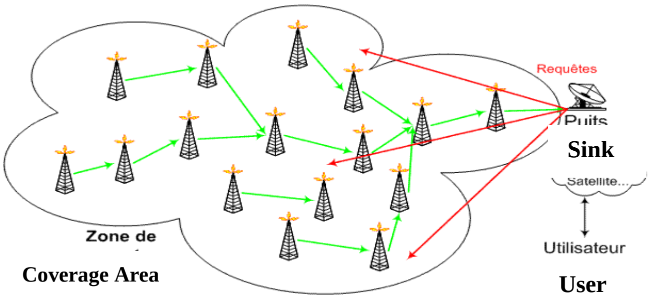

Fig.4. Information Collection on demand.

2.3.2. Information collection following an event

If an event occurs at a point in the coverage area (abrupt temperature change, motion, etc.), the nearby sensors then trace the collected information back to the sink.

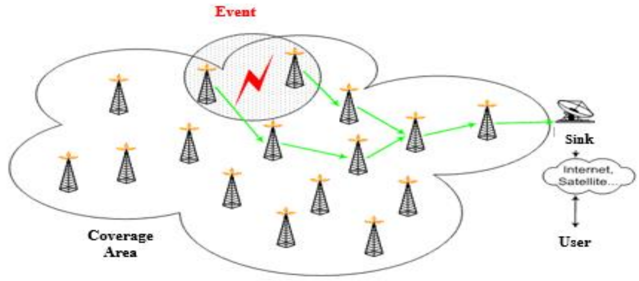

Fig.5. Information collection following an event.

2.4. WSNs topologies

In the Wireless Sensor Networks, there are two kinds of topologies: physical and logical topologies.

2.4.1. Physical topologies

A physical topology is usually the architecture definition of such a network. It represents the physical arrangement or the organization of the sensors, that is to say, the spatial configuration of the network. Such examples of topologies: the Random, Grid and chain topologies which are respectively represented by figures (Fig. 4, Fig. 5 and Fig.6).

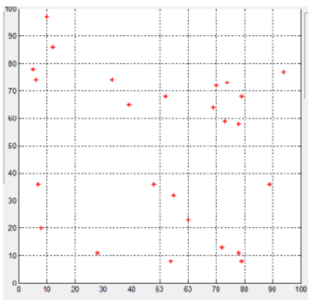

Fig 4. Random topology.

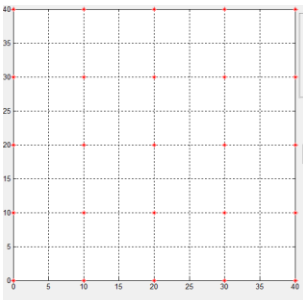

Fig 5. Grid topology.

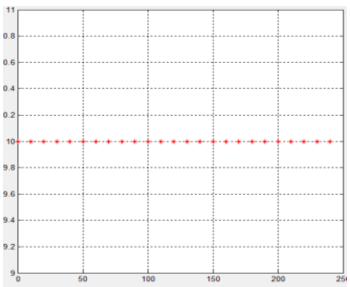

Fig 6. Chain topology.

4.2.2. Logical topologies

The logical topology of a WSN defines how or where data flows, or also the communication links whose nodes are interconnected. It depends on the protocol and the application used, such as routing protocols, data collection or aggregation, etc. This topology plays a major role in the operation of any protocol, as well as its performance. In a general way, these topologies can be classified into three main categories: flat topology, tree topology, and cluster topology (Fig.7, Fig.8 and Fig.9). The advantages and disadvantages of logical topologies as well as the main protocols that represent each category are summarized in the following table.

Table1. Protocol examples and their corresponding topologies with their advantages and disadvantages.

Used Topology	Advantages	Disadvantages		Protocol Examples	
Flat	- Offers good road qualities to the Sink. -Needs no topology maintenance	- Several redundant messages circulate in the network which consumes the energy . Transmissions are often delayed by overlap.		SPIN [7]	
Based on cluster	-The node energy consumption compared to the other topologies is reduced. - Extend network lifetime with better use of channel band width.	- Head clusters are the nodes that die most quickly. - Network connectivity can't be guaranteed.		LEACH [8]	
Tree topology	-Offers good road qualities to the Sink. - Saves more energy than flat topology	- The failure of a parent isolates an entire tree part - The problem of the energy hole that affects the nodes near the Sink.		CTP [9].	

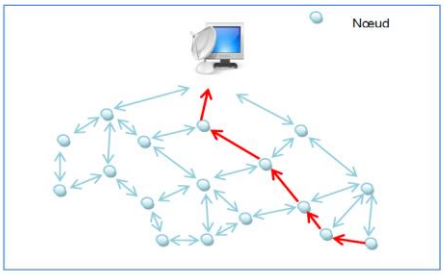

Fig 7. Flat topology.

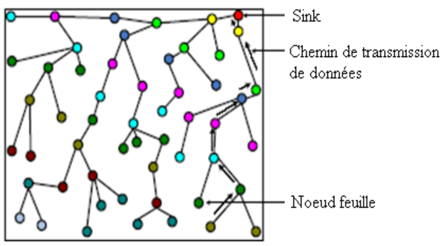

Fig 8. Tree topology.

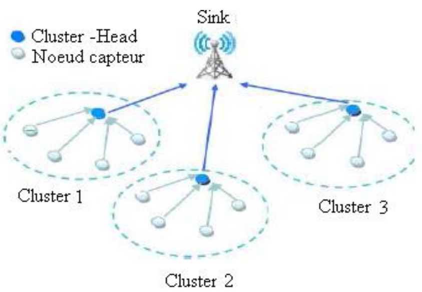

Fig 9. Topology based on clusters.

4.2.3. Topology control

Topology control is the use of network parameters to generate or maintain a topology that ensures proper operation. This is an important technique used in sensor networks to save energy and extend their life. The idea of topology control is to allow sensor nodes to control certain parameters that are manipulated in a way that optimizes operation. In particular, the sensor nodes have the ability to adjust the transmission power of their radio module or change their operating modes or choose the communication links to use which causes topological modifications. To build a topology, each sensor node discovers its neighbors and relative links using its maximum transmission power. The drawback is that a network may be too dense with too much interference. To avoid this problem, an appropriate topology check must be done to eliminate unnecessary links [10]. The main purpose of a topology control technique is to ensure network connectivity. Indeed, after the deployment of a wireless sensor network, we obtain a physical topology that cannot be changed, especially if the nature of the network used prevents the possibility of moving or adding nodes or changing their radio range. The solution is to modify some parameters to have a logical topology as needed.

2.5. Optimization of energy consumption in WSN

The first step in sensor energy system design is to analyze the power consumption characteristics of a wireless sensor node. This systematic analysis of the sensor node energy is extremely important for identifying problems in the energy system and for enabling efficient optimization. The sensor energy consumed is mainly due to the following operations:

- Data acquisition
- Communication (Radio)
- Data processing

The total energy consumed by a sensor is given by the following equation [1]:

$$E_{total} = E_{capture} + E_{processing} + E_{radio} \quad (1)$$

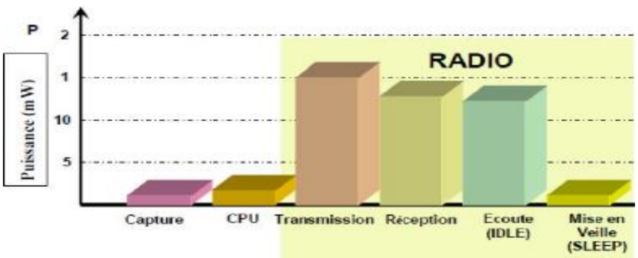

Fig.10. Energy consumption in a sensor node.

Figure 10 shows that the radio part energy occupies the largest portion of the total energy consumed by a sensor node.
As a result, the lifetime optimization of a WSN amounts to managing the energy consumption of this portion.
So, we need to focus on this Radio part to minimize this energy consumption due to routing via the Leach routing protocol. In what follows, a presentation of this protocol as well as the optimization strategy will be detailed.

3. Optimization strategy via Leach routing protocol

Nowadays in WSN, numbers of routing protocols have been proposed for WSN but most well-known protocols are hierarchical like LEACH and CTP. Hierarchical protocols are defined to reduce energy consumption by aggregating data and to reduce the transmissions to the base station [13]. For this reason, we have chosen these two famous protocols to compare and use the best of them in terms of energy consumption for our application in a smart home.

3.1. LEACH protocol

LEACH protocol (Low-Energy Adaptive Clustering Hierarchy) is not only a typical representation of hierarchical routing protocol but also a TDMA based MAC protocol. The aim of the LEACH protocol is to improve the lifetime of wireless sensor networks by lowering the energy.

3.2. LEACH protocol Architecture

LEACH divides the network into distributed zones and clusters, CH (Cluster-Head) nodes are constituted and then used as relays to reach the sink by optimizing consumption of energy using an algorithm that uses the randomized rotation of the group heads (CH) for equitably distributing the energy load between nodes in the network. A node decides which cluster to join on the basis of the strength of the signals received. When groups are formed as shown in figure 11, all non-CH nodes transmit their data at the group head. When the CH receives data from all members of the group, performs data processing functions (data aggregation and compression), and transmits them to the base station (BS) according to uni-cast communication (one hop).

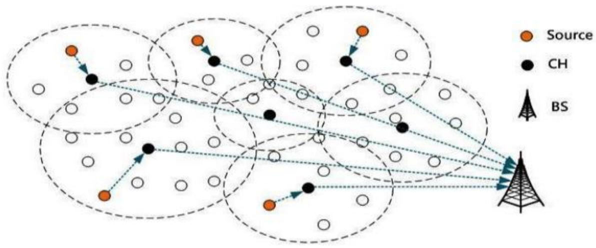

Fig 11. LEACH hierarchical routing architecture.

LEACH protocol is self-adaptive and self-organized [12]. It uses round as unit. This protocol operation consists of several rounds with two phases in each round.

- Set-up phase
- Transmission phase

Step1:Set-up phase

In the set-up phase, the main goal is to make a cluster and select the head for each cluster by choosing the sensor node with maximum energy. Set-up phase has three fundamental steps:

- Cluster head advertisement
- Cluster set up
- Creation of transmission schedule

During the first step cluster head sends the advertisement packet to inform the cluster nodes that they have become a cluster head on the basis of the following equation [13]:

$$T(n) = \frac{P}{1 - P.(r \bmod P^{-1})} \qquad \forall n \in G$$
$$T(n) = 0 \qquad \forall n \notin G \quad (2)$$

where
n is a random number between 0 and 1.
P is the cluster-head probability.
G is the set of nodes that weren't clustered heads the previous rounds.

T (n) : is the threshold.
r: is the current turn.

A. Cluster head advertisement

Initially, when groups are created, each node decides whether or not to become a CH for the current tour. This decision is based on the suggested percentage of CHs for the network and the number of times that the node has been a CH so far. This decision is made by the node through the choice of a random number between 0 and 1. If the number is less than a threshold T (n) the node becomes a CH for the current cycle. The nodes that were CHs must wait until (1 / p) turns. So, increasing the probability helps to increase the chance for non CH to become CH. The nodes are again eligible to become CHs if and only if all the nodes have once obtained the quality of CH. This is useful for balancing the energy consumption.
Each node that will be designated CH for the current turn broadcasts an “initialization” message to the rest of the nodes surrounding it. During this initialization phase, the CHs use the protocol CSMA (Carrier Sense Multiple Access) Media Access Control (CSMA). The other nodes must keep their receivers tuned in order to hear the messages posted by the CHs, and each of these nodes decides which group to join for the current turn based on the power of the messages received from the CHs. The more a node is close to the CH, the more the received signal gets stronger, indicating to the latter that he will need less energy to transmit its data to the CH. If two received signals have the same power, then the CH to join is chosen randomly.

B- Cluster set up

After each node has chosen which group to join, the CH must be informed of the nodes composing his group. All non-cluster head nodes send joint request to their cluster heads informing them that they are members of the clusters under that cluster heads.

C- Creation of transmission schedule

In the third step, after receiving requests from all the nodes that have joined, the CH allocates each a turn in TDMA (Time Division Multiple Access) a transmission scheduling based on the number of nodes. And it is only during the time allotted to them that the nodes can transmit their data to the CH.

Step2: Transmission phase

Once the groups have organized themselves and the TDMA program is put in place, cluster nodes send their data to the cluster head. The member sensors in each cluster can communicate only with the cluster head via a single hop transmission. Cluster head aggregates all the collected data and forwards data to the base station either directly or via other cluster head along with the static route defined in the source code. The other non-cluster head nodes of the group, of which it is not the turn, save a lot of energy by turning off their transmitter all the time and turn it on only when they have something to transmit to the cluster head in order to avoid the unnecessary dissipation of energy. But the CH must keep its receiver on during the current tour to receive all the data sent by the member nodes. After the transmission data is complete, the network again goes back to the set-up phase. This gives the transmission phase.

3.3. CTP protocol

CTP (Collection Tree Protocol) is a hierarchical routing protocol, which maintains a tree topology of a wireless sensor network. The nodes form a set of paths to the root using a routing gradient called ETX (expected transmissions). CTP uses routing through messages, also called beacons for building and maintaining the topology, and data packets to report the data of the application in question to the sink.

3.4. CTP protocol architecture

The implementation of the CTP protocol consists of three main logical software components:

• Routing Engine (RE).
• Forwarding Engine (FE).
• Link Estimator (LE).

A- Routing Engine (RE)

The RE (Routing Engine) is an instance that runs on each node and allows you to send and receive routing messages called beacons. It also allows creating and updating the routing table. This table is filled using the information extracted from the beacons. It contains a list of neighbour nodes with their identifiers along with the ETX (Expected Transmission) value, which is the metric that indicates the "link quality" via such neighbouring node (to the network coordinator). This ETX is extracted from the beacons as a result of a beacon exchange process between neighbours.
A node will select its parent (next hop or path towards network coordinator) in the routing tree from this table. First of all, for each of the neighbour nodes, $ETX_{link\ to\ parent}$ (ETX_{1hop}) is computed. The node then sums up this value with the ETX that the corresponding neighbours had declared in their routing beacons. The result of this sum is the $ETX_{multihop}$. After the update of all $ETX_{multihop}$ for all neighbours, the node selects the neighbour with the lowest $ETX_{multihop}$ as its parent.

$$\mathbf{ETX}_{root} = 0 \qquad (3)$$
$$\mathbf{ETX}_{node} = \mathbf{ETX}_{link\ to\ parent} + \mathbf{ETX}_{parent}$$

• ETX_{root} = ETX of the sink node.
•$ETX_{link\ to\ parent}$ = the link quality of the current node-neighbour link.
• ETX_{parent} = ETX of the current parent node**.**

B- Link Estimator (LE)

The module LE (Link Estimator), deals with the determination of the metric, which expresses the quality of the links between two nodes, which is the ETX_{1-hop} ($ETX_{link\ to\ parent}$). In addition, it creates and updates the link estimation table.

C- Forwarding Engine (FE)

The Forwarding Engine (FE) module is responsible for performing several tasks, the most important of which are:

- It handles the transmission of data packets.
- It decides whether or not the node has to transmit packets as well as the moment of transmission.
- It detects routing contradictions and informs the routing engine.
- It composes the packet for transmission and calls the transfer functions.
- It checks if there is a space in the queue
  - If yes, the post office sends the task.
  - If no, the bit responsible for congestion (c) will be set to 1.

3.5. Case Study: Smart Home

In this section, it is suggested to apply the Leach Communication Protocol on the wireless sensor network of a smart home the chosen design of which is given in accordance with the following figure.

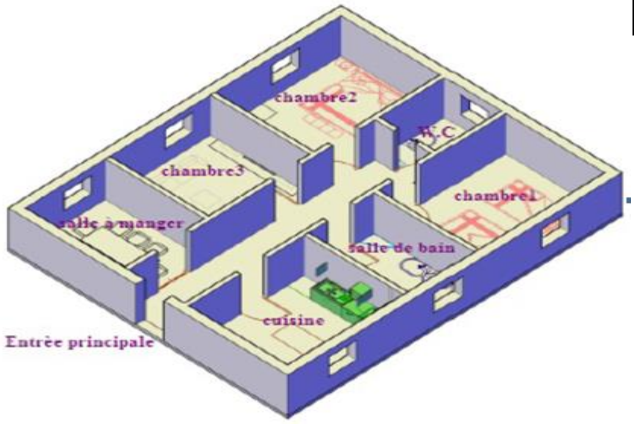

Fig 12. Smart home design.

The various sensors installed in this house are the temperature sensor, humidity sensor, brightness sensor, gas sensor, smoke sensor, pressure sensor, presence sensor, etc.

4. Results and discussions

In order to evaluate the simulated approach performances, to check the possibility of practical realization and finally to identify the optimization factors to improve performances, we have made a comparison between the routing protocols LEACH and CTP.
The wireless sensor networks were simulated under the OMNeT ++ / CASTALIA environment. As a result, the following parameters are taken into consideration:

1. The network size as well as the topology used are specified at the beginning of each simulation.
2. Node 0 is chosen as Sink.

The chosen wireless sensor network has 49 sensor nodes. To discuss the performance of both protocols the LEACH and the CTP, OMNet ++ / CASTALIA allows us to extract energy consumption data and other performance factors which are discussed in the light of the results provided by this simulator. Several simulations were conducted by CASTALIA to analyze the behavior of the protocols. The performance metrics calculated through the simulations are the energy consumption as a function of time, and the lifetime of the network .The curves obtained by simulations are followed by interpretation explaining the behavior of the network.
In order to determine the consumed energy by the wireless sensor network, we used the resource manager module (Resource Manager) in CASTALIA environment. It keeps track of the spent energy by the node and holds some specific quantities at the node. The resource manager calculates the consumed energy each time we have a power change or periodically.
Thus, two simulations of wireless sensor network for each protocol of one surface (25x25) meters were carried out for two different times in order to see the consumed energy by the nodes: the first test consists in choosing a simulation time equal to 100s and the second test for a simulation time equal to 500s. .

Test 1: Consumed energy for 100 seconds of simulation (LEACH protocol)

The simulation parameters are given in the following table:

Table 1. Parameters of the test 1.

Simulation time	100s
X field	25
Y field	25
Number of nodes	49
Topology	Grid « 7x7 »

During a simulation period, the number of transmissions and receptions of packets between the nodes of a wireless sensor network increases in accordance with time. This is why the energy consumed by each of the nodes used to make this traffic increases as well. This phenomenon is confirmed by figure 13, where we took an example of consumed energy of the node number 10 of a network consisting of 49 nodes distributed with a grid topology (7x7) and that during a period of simulation equal to 100s as indicated in the table of parameters (Table 1). We noticed that the consumed energy increases as a function of time until reaching the value 1,50293 Joule.

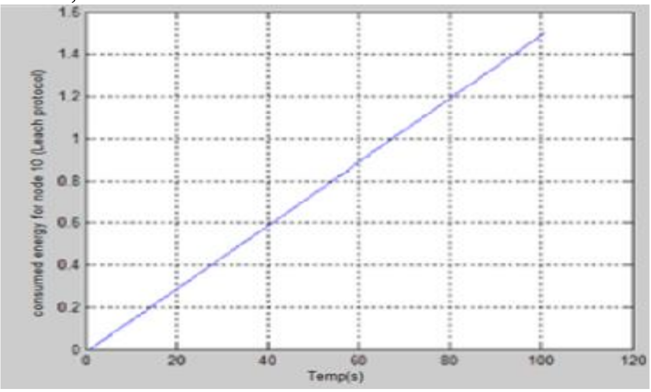

Fig.13. Consumed energy for node number 10 during 100s of simulation for LEACH protocol.

Test 2: Consumed energy for 500 seconds of simulation (Leach protocol)

If we are sure that the pace of the consumed energy curve will not be changed over time, we can then estimate the lifetime of each sensor node and get an idea of the network state in the future. For this reason, we must ensure that the LEACH protocol keeps this phenomenon by increasing the time, we then did another test using the same parameters except that we increased the simulation time further from 100s to 500s (Table 2).

Table 2. Parameters of the test 2.

Simulation time	500s
X field	25
Y field	25
Number of nodes	49
Topology	Grid « 7x7 »

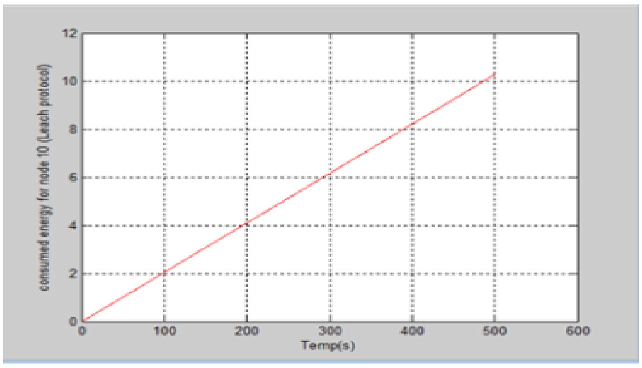

Fig 14. Consumed energy during 500s of simulation for LEACH protocol.

We notice that the curve keeps its pace and the consumed energy increases from 1,50293 Joule to 10,2878 Joule (Fig 14). So, we can calculate the network lifetime based on this pace.

Test 3: Consumed energy for 100 seconds of simulation (CTP protocol)

Same principle for CTP protocol.

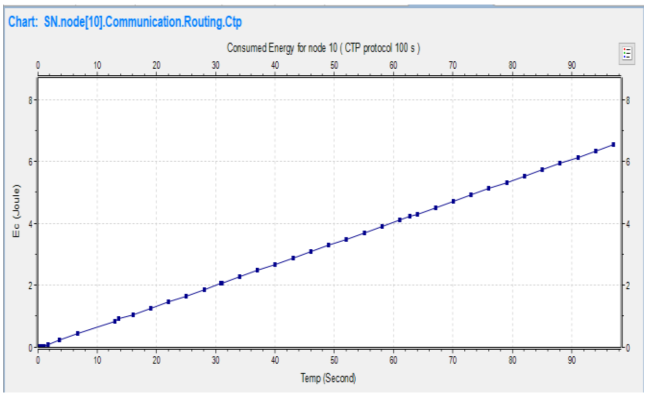

Fig 15. Consumed energy during 100s of simulation for CTP protocol.

Test 4: Consumed energy for 500 seconds of simulation (CTP protocol)

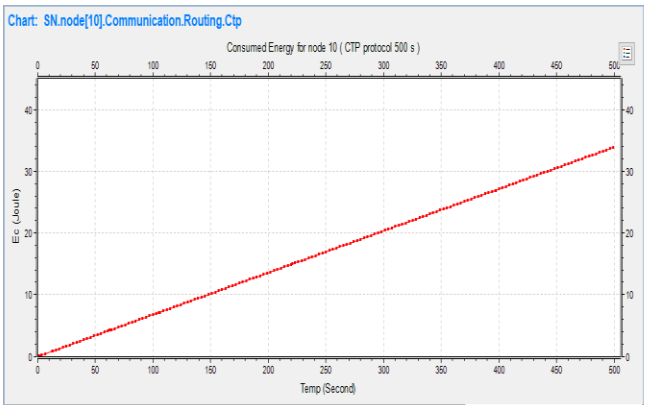

Fig 16. Energy Consumed during 500s of simulation for CTP protocol.

We notice that the curve keeps its pace and the consumed energy increases from 6,5497 Joule to 33,8857 Joule (Fig.15-16). So, we can calculate the network lifetime based on this pace for both protocols.
In order to test the efficiency of the chosen protocol, we have made a comparison of the consumed energy variation of the LEACH protocol with that of the CTP protocol.

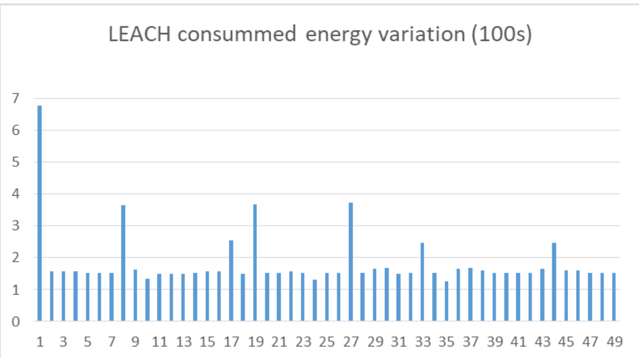

Fig.17. Consumed energy varation of the LEACH protocol for 100s.

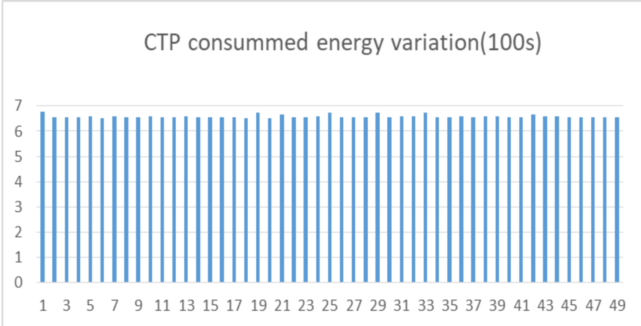

Fig.18. Consumed energy variation of CTP protocol for 100s.

By comparing the consumption energy variation of the LEACH and CTP protocols indicated respectively by figures 17 and 18, it can be noted that the LEACH protocol consumes energy less than the CTP protocol.

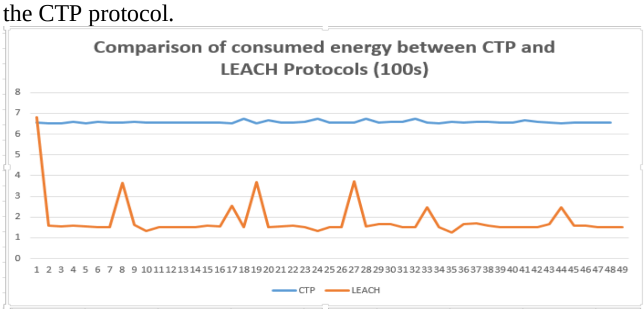

Fig 19. Consumed energy variation during 100s for the CTP and LEACH protocols.

According to Figure 19, we deduce that, despite the load balancing of the various network nodes provided by the CTP protocol, the latter consumes more than 6 times energy for the majority of nodes compared to the LEACH protocol. On another hand, this latter has some consumed energy peaks at nodes 7, 16, 18, 26, 32 and 43 which represent the CHs. These nodes consume more than the members because of the different actions that they must undertake and because of the energy required to transmit to the sink which is further than the distance which separates it from the members. In addition, these CHs must keep its receiver on during the current tour to receive all the data sent by the member nodes, but The other non-cluster head nodes of the group, of which it is not the turn, save a lot of energy by turning off their transmitter all the time and turn it on only when they have something to transmit to the cluster heads, in order to avoid the unnecessary dissipation of energy.
So, the CH nodes risk their failure in relation with the rest of the nodes as a result of their depletion and consequently the network disconnection. Despite this drawback, the results of the LEACH protocol for the minimization of consumed energy in WSN remain very satisfying compared to the CTP protocol.
Based on the consumed energy curves as a function of time of the two protocols CTP and LEACH represented previously, it was possible to estimate the lifetime networks of 49 nodes using these two protocols which are given by the following figure.

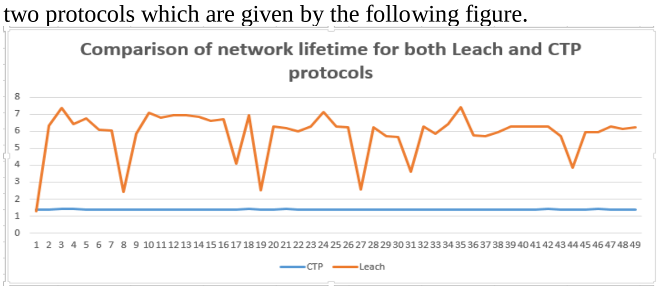

Fig.20. Lifetime Nodes for LEACH and CTP protocols.

We can see from these curves in figure 20 that the WSN lifetime based on LEACH protocol is more significant compared to the network lifetime based on CTP protocol. Indeed, the LEACH has in average 5.85 years for each node but for the CTP, it has only 1.39 years. These results confirm the LEACH protocol robustness compared to CTP protocol. Also, this result confirms the load balancing phenomena between the nodes seen in the previous test of the consumed energy variation by CTP protocol where the network nodes have almost the same lifetime with a minimal difference of one day or more, which explains the balancing of load between nodes. On the other hand, as for the LEACH protocol, we observe that the nodes 8, 17, 19, 27, 33 and 44 have a minimum lifetime compared to the other nodes of network. This proves well the result obtained in the previous section. Accordingly, the wireless sensor network, which uses LEACH routing protocol, can live more than the network based on CTP protocol.

5. Conclusion

In this paper, we have tried to optimize the energy consumption of the wireless sensor network by the LEACH protocol. Thus, the use of the OMNeT ++ / CASTALIA simulator allowed us to test our approach and extract some results to evaluate its performance. These results show the advantage of the LEACH protocol for the operation of WSNs. Indeed, our protocol improved the lifetime of the wireless sensor network by lowering the energy consumption of the network nodes.

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