Tree-Corr: A New Optimization Approach for Energy Saving in the Wireless Sensor Network

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Abstract

In wireless networks, routing protocols allow establishing routes between nodes to route packets between them. However, in sensor networks, routing protocols establish routes between any network node and the base station to ensure routing fidelity. In this respect, several protocols have been proposed in the literature. There are new protocols that have been developed as there are protocols that are improvements to others and try to fill the limitations of the original versions. In this work, we propose a new optimization technique for energy saving for wireless sensor networks called Tree-Correlation (Tree-Corr) using the tree structure as a routing protocol to reduce the data transmission distance of nodes at the base station. We propose three scenarios for our approach according to the method of deploying nodes in the area of interest. The simulation results show that the first scenario offers energy efficiency compared to the other two scenarios.

Keywords Wireless sensor network, Routing protocols, Energy Saving, Residual energy, Network lifetime, Tree-Corr.

1. Introduction

Technological advances made in the fields of microelectronics and wireless communication have made it possible to design and manufacture miniaturized, autonomous, and reliable components such as sensors [1]. Indeed, they are deployed over a large geographical area forming a network of sensor nodes to collect information on well-defined events, and to route them to a particular processing node, called a sink or a base station (BS). The information collected is used to build a global vision of the area covered to make decisions.

However, controlling energy consumption by sensor networks and maximizing their lifespan remains the most fundamental issue because sensors are small components with low storage and computing capacity and are powered by batteries. Whose capacity is very limited and which is generally not rechargeable. For example, in certain applications where the sensors are deployed in hostile areas, it is difficult or even impossible to change the batteries. This is the case for applications designed for global warming and monitoring the temperature variation at the North Pole where it is not practical to set up a team or send them each time to change the batteries of the sensors. So, for a network of sensors to remain autonomous for a long period (a few months or a few years) and subsequently have maximum longevity, energy consumption must be taken into account at all levels of the network architecture (from the physical layer to the application layer).

Recent advances in wireless sensor networks have led to the development of many protocols specifically designed for sensor networks where energy presentation is a critical factor [2].

Energy conservation is a key issue in the design of systems based on wireless sensor network (WSN). The hierarchical routing protocols have been developed in order to reduce network traffic to the BS and therefore extend the life of the network.

In the hierarchical structure, there are two main categories: the cluster structure and the chain structure. In the first case, the nodes are organized in clusters, each cluster having its cluster head (CH) to collect data and transmit them directly to the BS (one hop), or via intermediate nodes (multi-hops) [3]. In the second type, the node is organized into a chain. The data collected from different nodes in the chain is sent to the BS by the leader [4].

In the literature, several energy-efficient hierarchical routing protocols and algorithms for WSN have been proposed in order to save energy and therefore extend the life of the network.

In our article, we will present and implement the Tree Correlation (Tree-Corr) protocol, in order to study the impact of the protocol in the problem of energy consumption and make a comparative study between three scenarios proposed using Borland C ++ Builder 2010 version 14.0 environment.

The rest of this paper is organized as follows. In Section 2, we describe some similar works. Section 3 explains our proposed approach. In section 4, we give an evaluation of the performance of the proposed approach via the simulation results and its analysis. Finally, Section 5 concludes our paper, and some perspectives are pointed out.

2. Similar Works

In this section, we present some existing works in the literature relating to the saving of energy consumption in WSN. We first discuss hierarchical cluster-based routing protocols, then hierarchical chain-based routing protocols.

2.1. Cluster-based hierarchical routing protocol

This type of protocol has been widely followed by the research community in order to achieve the goal of energy saving in WSN. Here we present some research that uses clustering-based hierarchical routing as a mechanism to save power consumption in WSN.

Oualid et al. [5] have proposed a solution consists of using the data reported by the nodes in the WSN because they are in most cases correlated in time and space. Oualid et al [5] defined a new integer binary linear program to solve the problem of energy minimization under data precision constraints (EMDP). This program helps determine the most suitable nodes and gives each of them a specific role in data collection based on data correlation. Given the complexity of EMDP, Oualid et al. [5] proposed a heuristic solution called CORAD to structure the network topology in reconfigurable multi-hop clusters. For the scalability of the system, Oualid et al [5] used a dynamic clustering protocol with a dual objective: The first objective is setting up a local data fusion (or aggregation) center instead of a global center to reduce the length of routing paths and reduce the communication overhead due to network reconfiguration. The second objective is adapting the topology of the network according to the correlation of spatiotemporal data generated by the sensors. Since communications are the predominant cause of energy depletion, the initial election of CHs is based on their proximity to their neighboring nodes and their residual energy (static clustering). The spatio-temporal correlation is then integrated to design CORAD by adapting the topology of the network via two complementary mechanisms: adaptation of the behavior of the nodes and reconfiguration of the topology. The adaptive dynamic clustering algorithm presented in [5] works in two phases: the initialization phase and the reconfiguration phase. In the initialization phase, the algorithm takes three parameters as input: the direct neighbor information, the residual energy levels of the nodes, and the list of nodes with correlated values. At the output, it determines the clusters build according to the nature of the phenomenon monitored. The configuration procedure depends on the number of nodes in the cluster in round *t*, and the Mean Square Error (MSE) in round *t*. The results of numerical simulations of different scenarios prove that the CORAD solution proposed is an acceptable solution to the EMDP problem.

The objective of the work presented in [6] is to propose a hierarchical routing approach called LEACH-M (LEACH-Modified), based on the dynamic partitioning of the network into a set of clusters. Each cluster constitutes sensor nodes represented by a CH. The latter is selected according to a selective process based on the optimization of resources. The proposed hierarchical routing protocol must ensure optimal network operation by minimizing the consumption of energy resources and end-to-end information delivery times. The implementation of this protocol goes through three operational phases: a cluster announcement and creation phase, a scheduling phase, and a transmission phase. In this protocol, the data processing at the level of each cluster is done locally and the role of each CH is to coordinate the exchanges with the other simple member nodes. The network has the capacity to self-reorganize during the election phase of the CHs. Each node has the possibility of being elected CH and vice versa, each CH can again become a simple member node that can belong to a cluster. The election of a CH is based on energy criteria. The more energy the node has, the more it can become CH. To test the efficiency and show the performance and improvements of the proposed approach, the authors of this work performed a comparative study with the standard LEACH routing protocol. The experimental results obtained show that the LEACH-Modified protocol has better performance than those of the LEACH protocol. The number of messages exchanged between the various simple member nodes and the CHs is strictly lower in LEACH-Modified than in LEACH. It is the same for the number of inactive nodes which is strictly lower in LEACH-Modified compared to LEACH. These results reflect better optimization of resources in LEACH-M than in LEACH and therefore greater network longevity when implementing the LEACH-Modified protocol.

In order to reduce energy consumption for WSN, Wang et al. [7] proposed a new coverage control algorithm based on Particle Swarm Optimization (PSO) called SRAAC (Sensing Radius Adaptive Coverage Control algorithm). In order to achieve a balance between coverage rate and power cost, the detection radius of each node must be adjusted. In the initial phase, Wang et.al. [7] considered that m sensor nodes are randomly deployed in the target area and remain static after deployment. The detection radius Ri of each sensor is initially set in the same way. Then they partitioned the network into several grids. They then calculated the energy consumption and coverage rate for each network. In order to adjust the detection radius of nodes in different networks, they adopted a PSO technique [8] in the last phase. The simulation results show that the proposed SRAAC algorithm can effectively improve the coverage rate and reduce energy consumption compared to other PSO-based variants presented in the literature.

2.2. Chain-based hierarchical routing protocol

A variation of hierarchical routing protocols is to build chains instead of clusters. In what follows, we present some research works that exist in the literature related to the topic of energy saving in WSN.

The objective of the algorithm proposed in [9] is to improve the PEGASIS protocol by proposing an algorithm called EPEGASIS (Enhanced PEGASIS). This algorithm belongs to the chain-based routing algorithms. In EPEGASIS, each node uses an optimal communication distance to choose the relay node among its neighbors for data transmission. In order to avoid excessive power consumption for certain nodes with a particular location, Wang et al. [9] defined a protection mechanism based on the average residual energy of its neighbors. Mobile BS technology is used to collect data to balance energy consumption in different regions. After the nodes are deployed, the network enters the initial phase which is followed by the phase of generating the topology. The main purpose of the initial network phase is to exchange information to prepare for data transmission. In the phase of network topology generation, Wang et al. [9] mainly reduced data transmission times and achieved optimum power consumption. They use optimal communication and an optimal number of hops for data transmission. Many experiments have been carried out to prove that the EPEGASIS protocol offers better performance in terms of power dissipation, network lifetime and latency, compared to PEGASIS [4].

The protocol proposed by Hadjila [10] combines different tools to deal with the problem of energy conservation in routing. This protocol consists of three phases: cluster formation phase, CH selection phase, and data transmission phase. In the cluster formation phase, the formation of clusters is carried out by the FCM (Fuzzy C-Means) approach [11] [12]. The latter consists of forming a predetermined number of clusters; this number is chosen equal to the square root of the total number of nodes deployed. An Ant Colony Optimization (ACO) algorithm is used to build a local chain in each cluster. Then the greatest distance between two consecutive nodes is removed to get the shortest open chain. At the start of CH selection phase, a node is randomly chosen as the leader node since all nodes have the same amount of energy. For data collection and merging, each member of the cluster captures the data and then transfers it along the local chain to the leader node, which receives the data and aggregates it. When a node depletes its energy in a local chain, the latter is rebuilt by bypassing the dead node. Leader node rotation in each cluster is performed according to the remaining node energy.

In order to extend the life of the network, Young et al. [13] proposed a protocol called intra-Grid PEGASIS. The authors took PEGASIS as the basic protocol, and then they associated a grid with it. The nodes are evenly distributed in each grid. The process can be divided into three steps, namely, setting up the grid, deploying the grid, and chaining the grid. In setting up the grid, the amount of grid will be set up first, for example, setting up a 5 x 5 grid. In the grid deployment step, each node in the network will be evenly distributed. If the node number cannot be distributed equally to all the grids, the grid near the BS will have one more node. The chaining of the grid can be divided into two sub-steps: formation of the chain of nodes in the network and formation of chain between the grids. Initially, the greedy algorithm is used to form the chain of nodes inside the grid, this is called the grid chain. In the second step, this chain is called the domain chain. We follow the principle of left to right (odd row) or right to left (same row) so that the grids of a whole row are formed in a chain until the last grid. If this is the odd row, then the last grid is the grid on the far right side and inside the grid, there will be an end node and a start node.
Table 1 presents a comparison between similar cluster-bases works.

Table 1 Comparison between the similar cluster-bases works

Routing protocol	Architecture type	Type of sensors	Cluster classification	Clustering metric	Algorithm used for clustering	Number of hop
CORAD [5]	Centralized	Homogeneous	Dynamic	Data correlation, Residual energy, Data accuracy, Distance	Correlation-based adaptive dynamic clustering scheme	Multi-hop
LEACH-M [6]	Distributed	Homogeneous	Dynamic	Residual energy	Modified LEACH algorithm	one-hop
SRAAC [7]	Hybrid	Homogeneous	Static grids	Coverage, Energy cost	PSO	Multi-hop

Table 2 presents a comparison between similar chain-based works.

Table 2 Comparison between the similar chain-bases works

Routing protocol	Number of CH per chain	BS mobility	Data transmission to BS	Selection of the next node in the chain	CH selection factors
EPEGASIS [9]	Many Nearest neighbor proximity based on distance, residual energy of neighboring nodes Distance to BS (Based on PEGASIS)	Mobile	CH with multi-hop routing and one hop	Nearest neighbor based on distance, residual energy of neighboring nodes	Distance to BS (Based on PEGASIS)
[10] (Hadjila)	Many	Fixed	CH with multi hops	ACO	Energy residual
intra-Grid PEGASIS [13]	1	Fixed	CH with multi-hop routing	Nearest neighbor based on distance	Distance to BS

3. Our Proposed Approach

Our proposed approach is based on the tree structure to send data from nodes to the base station. It uses the principle of forming levels and zones where the area of interest is divided into several zones. The mode of data transmission from the nodes to the base station is by multi-hop between the different levels. We point out that the proposed protocol is centralized because the construction of the data path between the levels is done by the base station.

The objective of the proposed approach is to conserve the residual energy of the nodes which are close to each other of which one node sends the physical quantity detected in a small space (temperature for example) using the tree structure as a routing protocol to reduce the data transmission distance from the nodes to the base station. The proposed protocol makes it possible to reduce the number of nodes that communicate directly with the base station. Communication takes place between the nodes by forming chains between the child nodes and the father nodes (level n and level n + 1). For this, the area of interest is divided into four areas, and each area in turn is divided into four sub-zones with different levels (three levels) to obtain smaller spaces and therefore nodes closer to each other.

The sensors are distributed randomly with three scenarios:

- The first scenario: The number of sensors in each level is taken into account when distributing the sensors, including the number of sensors deployed in level n + 1 greater than the number of sensors deployed in level n.

-The second scenario: The distribution of the sensors is done in an equitable way between the four zones, but randomly in the sub_zones.

-The third scenario: The distribution of the sensors is done randomly in the four zones.

Fig. 1 below shows the levels of our simulation area.

Sub_zone1 (Level1)	Sub_zone2 (Level 2)	Sub_zone1 (Level 2)	Sub_zone2 (Level1)
Sub_zone3 (Level 2)	Sub_zone4 (Level 3)	Sub_zone3 (Level 3)	Sub_zone4 (Level 2)
Sub_zone1 (Level 2)	Sub_zone2 (Level 3)	Sub_zone1 (Level 3)	Sub_zone2 (Level 2)
Sub_zone3 (Level 1)	Sub_zone4 (Level 2)	Sub_zone3 (Level 2)	Sub_zone4 (Level1)

Fig. 1 The levels of the simulation area.

The data transmission between the nodes and the base station is identical for the three previous scenarios, the transmission is done in parallel in the four zones by following the following procedures:

- We select a single node that has a higher energy level among the nodes of the same sub_zones because they are close to each other and therefore they have almost the same value of the physical quantity detected (the temperature);
- The selected level 1 node chooses its father among the closest level 2 nodes.

- The level 2 node selected as the parent of the level 1 node aggregates its data with the data received.
- The selected level 2 nodes send their data to their father (node selected in level 3).
- The latter sends the detected and aggregated data directly to the base station.
- The above procedures are repeated until energy exhaustion.

Our approach is executed in several iterations, where each iteration goes through two phases:

3.1. Initialization phase (deployment phase)

The following figure (See Fig. 2) shows the flowchart of the initialization phase.

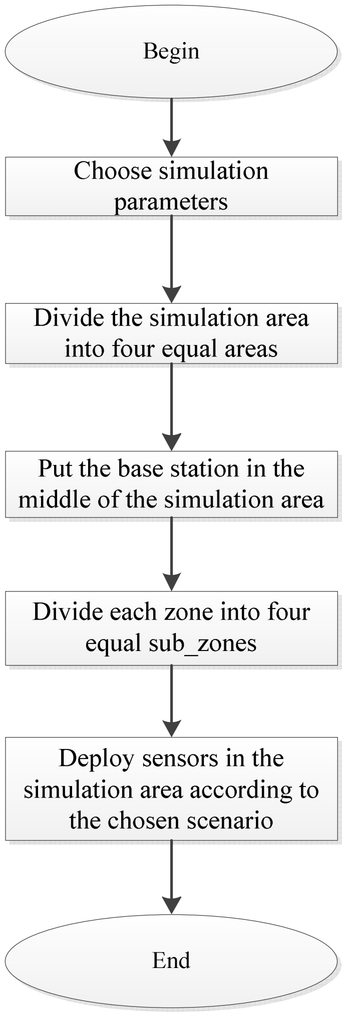

Fig. 2 Flowchart of the initialization phase (deployment).

3.2. The data transmission phase (tree construction)

In this phase the following processes will be executed:

- Select a node that has a higher energy level among the nodes of the same sub_zones;
- The selected node of level 1 chooses its father from the closest nodes of level 2;

- The node of level 2 selected as the parent of the node of level 1 aggregates its data with the data received;
- The nodes of level 2 selected send their data to their father;
- The node of level 3 sends the detected and aggregated data directly to the BS.

Fig.3 shows the flowchart of the data transmission phase.

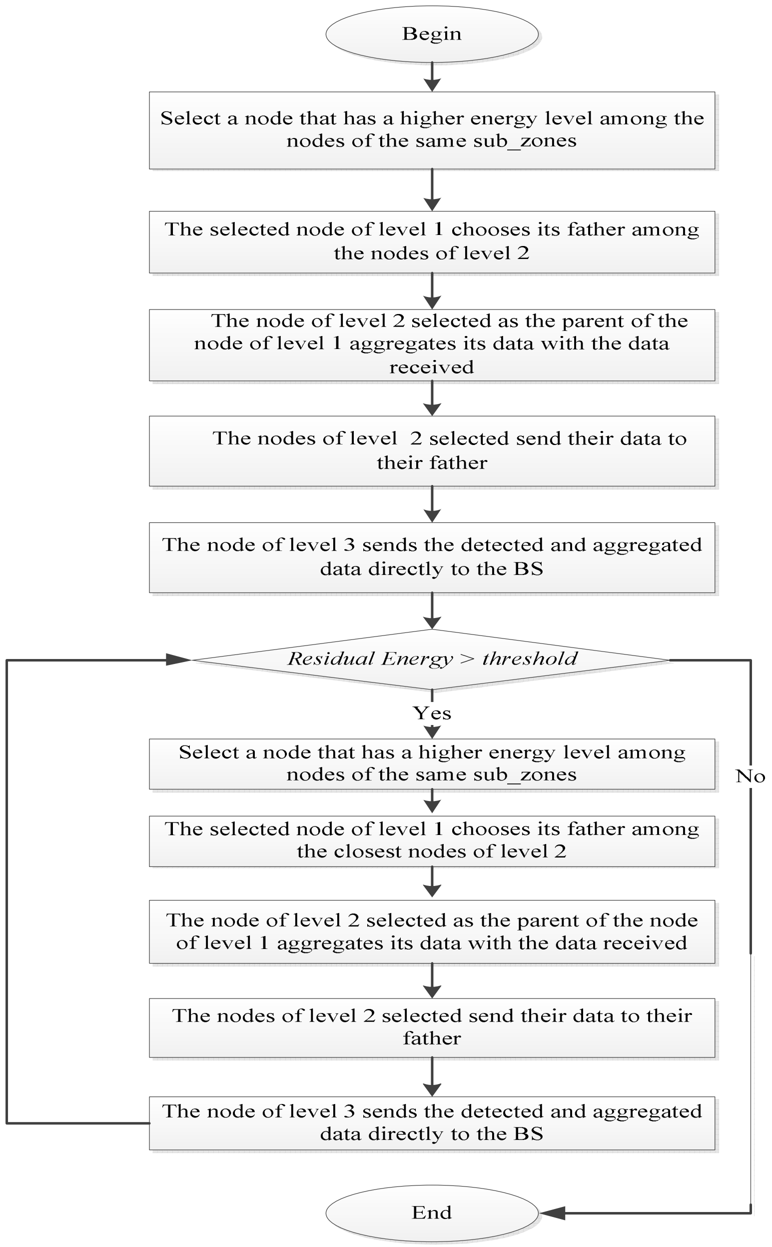

Fig. 3 Flowchart of the data transmission phase (tree construction).

4. Simulation Results

In order to calculate the energy consumed in data transmission operations and data reception operations, we use the energy model used in [14].

The energy consumption for the transmission of a packet of L bit at a distance d is given by the following equation:

$$E_{TX} = \begin{cases} L * E_{elec}(L,d) + L * \varepsilon_{fs} * d^2, d < d_0 \\ L * E_{elec}(L,d) + L * \varepsilon_{mp} * d^4, d \geq d_0 \end{cases} \quad (1)$$

Where;

- E_{TX} represents the energy consumed by the transmitter to send a packet of L bits over a distance of d meters.

- $E_{elec}(L,d)$ represents the energy sufficient to transmit or receive one bit over d meters.

- L represents the data size to be transmitted.

- ε_{fs} and ε_{mp} are the amplification energy that depends on the transmitter amplifier model.

- d_0 represents the threshold distance for which the amplification factors change their value.

The distance d_0 is calculated according to the following equation:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (2)$$

The energy consumed in the receiving operation is calculated according to the following equation:

$$E_{RX}(L) = L * E_{elec} \quad (3)$$

4.1. Simulation settings

The information shown in Tab. 3 is the parameters and their values used in our simulation.

Table 3 Parameters of simulation

Parameters	Values
Deployment zone	100m*100m
Coordinate of the BS	(50,50)
Number of sensors	100
Way of node deployment	According to the chosen scenario
Initial energy (E_0)	0.1 J/node
E_{elec}	50 nJ/bit
Data Packet Size	500 Byte
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4

4.2. Results and discussion

We performed several simulations of our Tree-Corr routing approach in the three scenarios and we kept the same simulation parameters cited in Table 3. The results of the figures below represent the average of these simulations.

4.2.1. Number of rounds

Fig. 4 represents the number of rounds for each scenario. From the results shown in Fig.4, we observe that scenario 1 of our proposed Tree-Corr approach has about 450 rounds. However, scenario 2 has about 150 rounds and scenario 3 has about 120 rounds. Therefore we conclude that the lifetime of scenario1 of Tree-Corr protocol is greater than the lifetime of two scenarios (2, 3) due to data transmitted to the BS and the residual energy in the network differs between the three scenarios.

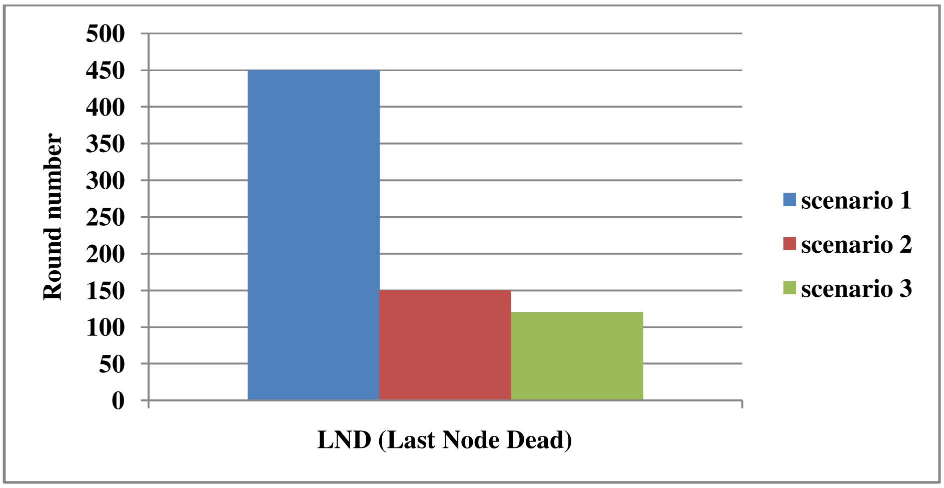

Fig. 4 Network lifetime of each scenario

4.2.2. Residual energy

The following Fig. 5 shows a comparison between these three scenarios in terms of the residual energy versus the number of rounds.

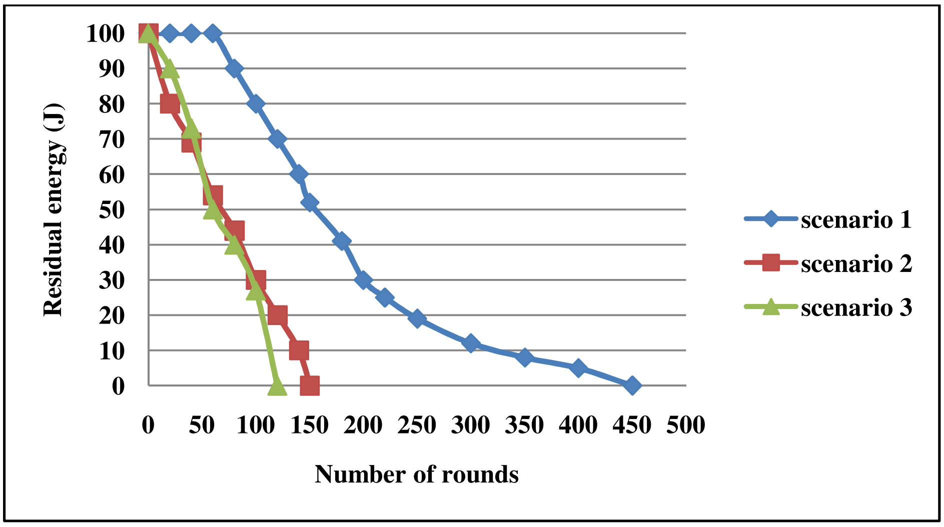

Fig.5 Residual energy over the number of rounds

From Fig.5, we observe that the residual energy of the network in the first scenario decreases regularly compared to the two other scenarios. The results of Fig.5 clearly show that the first scenario1 has better performance than the other scenario (2,3). This is because scenario 1 takes into account the number of sensors in each level when distributing the sensors.

5. Conclusion and Perspectives

We have presented in this article a new optimization technique for energy saving for wireless sensor networks called Tree-Correlation (Tree-Corr) using the tree structure as a routing protocol to reduce the distance of data transmission from nodes to the base station. We have proposed three scenarios of our proposed approach. From the comparison, we concluded that Scenario 1 works better than the other scenarios (2,3) in terms of minimizing energy consumption and therefore extending the network lifetime.

As a perspective, we propose the following points to improve the performance of our approach in the face of energy saving:

- Decrease the areas of the sub_zones to improve the correlation between the data.
- Examine the case of several scenarios and make comparisons between them.
- Consider the case of a mobile base station.
- Compare the proposed approach with other techniques existing in the literature to see their efficiency in the field of energy-saving in WSN.

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