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Research on the Energy Efficiency of the Wireless Sensor Network for Measurement of the Main Physicochemical Parameters of the Soil †

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Abstract

This article presents a study of the energy efficiency of a wireless sensor network for measuring the main physicochemical parameters of soil. The main physicochemical parameters of soil are measured—acidity and electrical conductivity. The study on the transmission of measured data on the main soil parameters is conducted through simulation, with program modules developed in the MATLAB environment. Four main protocols for data routing are studied—the LEACH (Low-Energy Adaptive Clustering Hierarchy), EAMMH (Energy-Aware Multi-Hop Multi-Path Hierarchical), SEP (Stable Election Protocol for clustered heterogeneous WSN), and TEEN (Threshold-sensitive Energy Efficient Network). The results of the main energy indicators are obtained and a comparative analysis of the two protocols is carried out. The results obtained show that the SEP and TEEN routing protocols have better performance and efficiency with respect to inactive nodes in the network compared to the other two protocols. The EAMMH and LEACH routing protocols are the best in terms of the energy consumption by sensors in the network.

Keywords: WSN protocols; MATLAB; precision agriculture

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1. Introduction

Since the end of the 20th century, data networks have seen a constantly growing interest. The penetration of fixed networks in many places around the planet has shown that connecting users to a network with wired transmission links creates inconveniences related to limiting their mobility. In this regard, wireless connectivity does not impose such restrictions and provides more freedom within the coverage area. In this sense, wireless networks and data transmission technologies are superior to traditional fixed networks.

Initially, these networks contain small and large nodes, called sensor nodes. The size of these nodes is not random, but strictly defined for the specific applications of the network. They are designed to contain microcontrollers that control monitoring, a radio transmitter that generates radio waves, various types of wireless communication devices, and a power source, most often a battery.

So far, the applications of these networks have been mainly related to monitoring various activities, such as the environment, traffic, weather, and so on. These networks can also detect the presence of vehicles from motorcycles to trains.

Some of the many advantages of these networks are as follows: limited energy storage, no cables, and high portability. These systems work well in extreme conditions and on a large scale. However, the technology also has its drawbacks—the communication speed is quite unsatisfactory and its use is still too expensive to become widespread [1].

Wireless communication technologies are characterized by the following attributes:

- High flexibility in building the network topology;
- Lack of cabling, i.e., absence of mechanical wear of the transmission medium;
- Possibility of mobility and free movement of devices in the network;
- Lower network traffic between the network endpoints, due to the higher degree of autonomy between the individual segments of the system;
- Ensuring the necessary speed of information transmission;
- Compatibility with standards used in industrial automation such as DeviceNet and Ethernet, etc.;
- Easy and quick start-up of devices included in the network, etc.

Modern WLANs usually establish a connection at distances from one to several hundred meters and transmit only digital data, and depending on their maximum speed, there are three groups of implementation technologies.

Due to the rapid growth of the wireless communication industry, many projects that monitor the environment wirelessly have been proposed and completed successfully all over the world [2]. A typical example of such projects is the use of wireless sensor networks (WSNs) to observe the environment of the Tungurahua volcano [3], where researchers deployed WSNs to monitor volcanic eruptions using acoustic sensors with low frequency. Another example is a study conducted by other researchers [4]. They developed a network of wireless sensor nodes to monitor the atmospheric environment. The advantage of the proposed network is the ability to add or replace any node at any time without influencing the network reliability capabilities (the so-called self-healing effect).

The careful consideration of specific requirements, related to the application of wireless sensor networks, is of great importance, especially when dealing with the monitoring of the environment. In [5], some guidelines for the implementation of WSNs in this difficult application are defined. They propose techniques for choosing certain parameters in order to provide a high level of reliability and network lifetime. There are also guidelines about how to deal with issues like network synchronization and data consistency.

A wireless sensor network contains hundreds or thousands of sensor nodes that can communicate with each other or directly send data to a base station [6]. Each sensor node includes a sensing part, a processing part, a transmitting part, a location detection system, and a battery. They are usually scattered in a sensor field, which is an area in which they must monitor certain parameters, communicating with each other to receive up-to-date information [7].

The main factor that makes wireless sensor networks attractive is their advantage of collecting and transmitting information about an area in which the human factor is minimized or completely impossible, and for a sufficiently long period of time [6,8].

A wireless sensor network consists of protocols and algorithms with self-organizing capabilities. They are needed to communicate and send data from one sensor node to another. There are many routing protocols, but work continues to create new and more efficient ones. Routing protocols are classified in many different ways.

Challenges to Wireless Sensor Networks

Different factors have an influence on wireless sensor networks and create limitations for its use, the main ones being as follows:

- Limited power management:

Different applications of wireless sensor networks are more power-consuming, but the power limitation sometimes causes problems in the functioning process;

- Lack of resources:

The resource limitation of sensor nodes is due to their small size. It affects memory, bandwidth, and consuming power;

- Scalability and mobility:

The sensor network nodes often move from their position, and this leads to communication problems between them;

- Dynamic network topologies:

Typically, no planning is applied in the deployment of sensor nodes, which leads to repeated changes in the network topology. Important reasons leading to such a change can be a change in the node position, physical damage, or power limitation;

- Adaptability:

The change in the nodes' positions can cause communication problems. For that reason, fast and adaptable algorithms must be used for rerouting;

- Data collection:

Data collection reduces the amount of energy used during data transmission between nodes. This increases the lifetime of sensor nodes;

- Quality of service:

Wireless sensor networks are used for a vast number of applications. Some of them are quite critical and need reliable service in a timely manner;

- Security:

It is very important for the communication between nodes to be secure. This ensures data confidentiality and integrity [8].

Routing is a method of sending data between two nodes using appropriate routing protocols, choosing the optimal path from the source to the destination node. The movement of incoming data is performed by the network layer. The energy of most of the starting nodes cannot ensure that the data reaches the destination due to their long distance, and in such a case, intermediate sensor nodes forward the packets. The BSM has some limitations, such as power supply, bandwidth, and others. The main part of routing protocols, which are designed for WSNs, are mainly focused on power consumption. The design of the protocols complies with the specific application and the type of network itself.

Routing protocols for wireless transmission [9,10] are grouped according to the mode of functions, the type of participation of the sensor nodes, and the network structure. The protocols in the first group are divided into active, reactive, and hybrid. The protocols in the second group can be flat, cluster-based, or direct. Protocols according to the network structure can be data-oriented, location-based, QoS (quality of service)-based, or hierarchical.

Data-oriented protocols depend on a label or name for the required data and deal with the elimination of redundant transmissions. They work in the following way: the base station sends requests for certain data from the nodes and if the data matches the request, the nodes send it back to the base station. Examples of this type of routing protocol are Directed Diffusion (DD), Sensor Protocols for Information via Negotiation (SPIN), and COUGAR, etc. The goal of hierarchical-based routing protocols is to enhance the energy

efficiency of the network. This goal is achieved by selecting nodes with higher energy to process and send the data to the base station or to an intermediate master node. Such protocols ensure energy-efficient routing in the BSM and are best suited to a reduction in the size of the total message transmissions. The most popular routing protocols in this category are Power-Efficient Gathering in Sensor Information Systems (PEGASIS), the Low Energy Adaptive Clustering Hierarchy (LEACH) [11,12], the Threshold-sensitive Energy Efficient sensor Network protocol (TEEN), and Adaptive Periodic TEEN (APTEEN) [13,14].

Location-based protocols need information about the location of sensor nodes, usually available from Global Positioning System (GPS) signals or strong radio signals. Routing protocols from this category calculate the distance to a neighboring node based on the incoming signal strength. The network nodes are in two states: active or sleep, in order to limit network losses. The most popular protocols in this category are Geographic Adaptive Fidelity (GAF) and Geographic and Energy-Aware Routing (GEAR).

In Quality of Service (QoS)-based protocols, the focus is on reliability and latency. Sensor networks are based on the function of network balance and quality, data quality, and energy efficiency. The most popular protocols from this category are Sequential Assignment Routing (SAR) [11,15] and SPEED (Stateless Protocol for Real-Time Communication in Sensor Networks).

This article presents a study of the energy efficiency of a wireless sensor network for measuring the main physicochemical parameters of soil.

2. Materials and Methods

2.1. Simulation Software

There are several software platforms that could be used for WSN analysis [16]. In this section, several software platforms for WSN simulation are described, with their advantages and disadvantages.

- Acrylic network software

The acrylic network analyzer (Figure 1) can monitor WiFi network packets and display wireless networks and their users like a standard scanner. It uses a graphical interface to display networks and clients and to show packet details [17]. The captured traffic details are viewed in real time using a unique packet dissector (the so-called WiFi network packet parser). There is also the option to use a predefined pcap file for network packet analysis. The software includes an integrated filter editor, with the help of which the WiFi network packet type can be selected for displaying. It also helps to indicate WiFi attributes and perform filtration via SSID or MAC address, etc. Another part of the software—the WiFi inventory module—can help to replace MAC addresses with common names.

The WiFi network packet analyzer is constructed from three main parts:

- WiFi network packet list: Displays the captured network packets and all the related data as well as the WiFi name;
- WiFi network packet structure: Shows attributes and frame-specific data as a tree structure;
- Hexadecimal viewer: Views network package content as hexadecimal numbers.

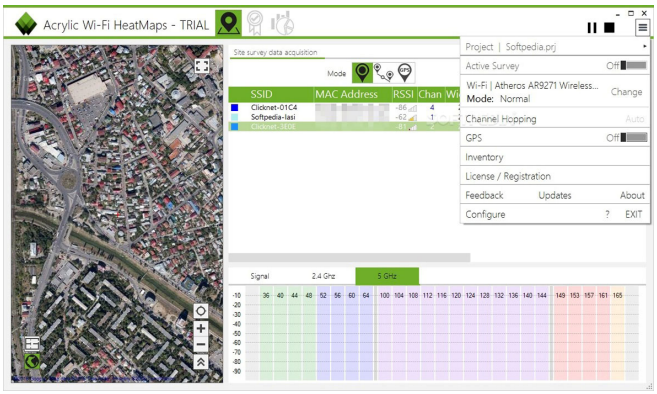


Figure 1. Acrylic network 4.5 software.

- Ekahau HeatMapper software

As the name suggests, it is network-mapping software (Figure 2). HeatMapper 1.1.2 is actually the free version of Ekahau's Wi-Fi Site and Survey Planner. It provides an attractive coverage graph and information on the security settings of detected Wi-Fi networks. It calmly analyzes networks, but has some difficulty with 802.11 ac.

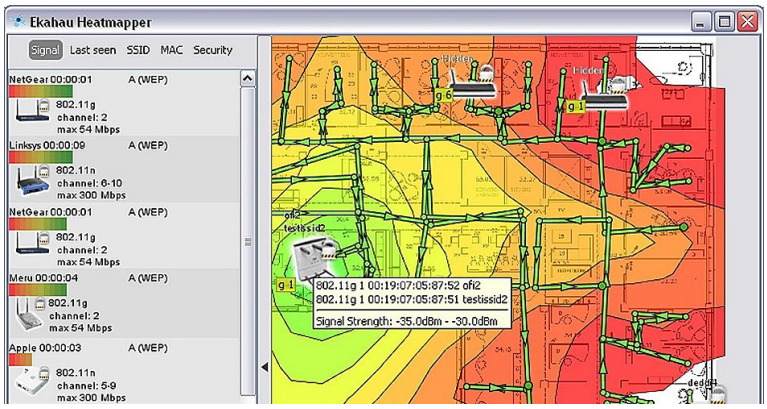


Figure 2. Ekahau HeatMapper software.

- Homedale software

Homedale is a relatively simple and portable Windows-based scanner with the ability to include a command line interface (Figure 3). In addition to providing signal strength and basic network information, it also supports GPS and other types of geo-tracking.



Figure 3. Homedale 2.20 software.

- MATLAB R2022b software platform

MATLAB (Figure 4) allows for the creation of graphical user interfaces for the simulation of neural networks. It allows the integration of multiple additional features to implement wireless sensor network parameters for the various communication interfaces. It allows the location of the modules on the surveyed area as well as the condition of the packets to be transmitted over the network to be determined.

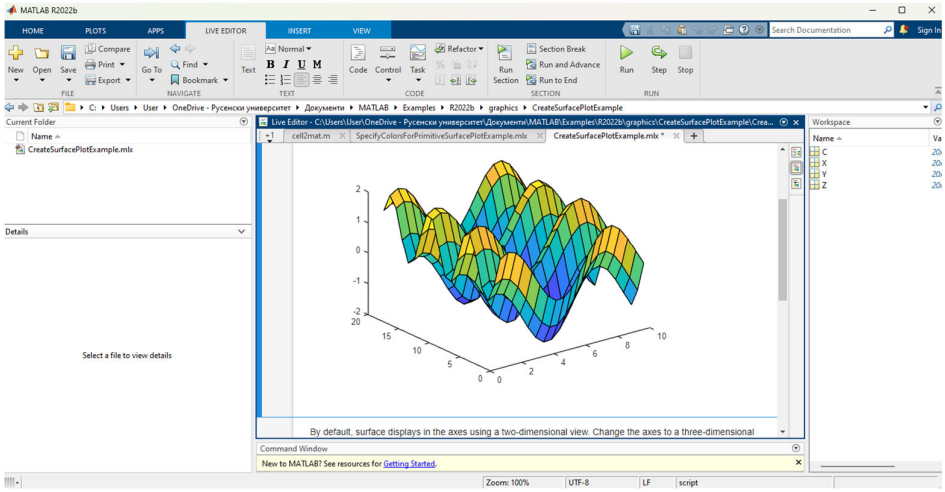


Figure 4. MATLAB software platform.

2.2. Energy Model of a Wireless Data Transmission Network

Route selection is the process of selecting a path from a list of possible paths, and that path is either part of the route or the entire route of a packet to its destination. This process involves applying routing metrics to multiple routes in order to select (or predict) the best routes.

A metric is a property of a route, consisting of various values used by routing algorithms to determine whether a given route is better-performing than another.

Metrics can include information such as bandwidth; network delay; packet loss rate; hop count; path cost; load; reliability; and communication cost.

Other metrics are built on techniques that may include metrics such as those mentioned above. Improving the metrics makes it easier to select better paths. In general, these metrics serve to represent the cost of a connection between two nodes in a network. Some of the most popular metrics are as follows:

- Expected Transmission Count (ETX)—this is the rate of packet loss during transmission between a pair of nodes;
- Round Trip Time (RTT)—this is the delay in exchanging (sending and receiving) packets between two nodes in a network;
- Hop Count—this is the number of connections between two nodes in a network.

The following energy model was used in the study, as presented in Figure 5. In the model, the parameters are as follows:

- d—the distance between the transmitter and receiver;
- L—the data packets that are transmitted;
- E_{TX}(L,d)—the energy required to transmit the data;
- E_{RX}(L)—the energy required to receive the data.

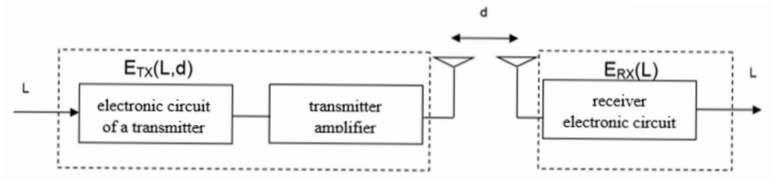


Figure 5. Energy model of a wireless data transmission network.

The simulation of the protocols was conducted at a probability of 5%. This is the percentage of nodes in the network that can be the heads of the clusters in it.

2.3. Experimental Results

The parameters used in the simulation of the protocols are presented in Table 1.

Table 1. The parameters used in the simulation.

Parameters	Value
Dimensions of the simulation area	100 m × 100 m
Energy source	Battery
ETX	50 × 0.000000001
ERX	50 × 0.000000001

The results of testing the developed program codes for studying the four routing protocols are presented in the following graphs.

The researched routing protocols are the LEACH (Low-Energy Adaptive Clustering Hierarchy), EAMMH (Energy-Aware Multi-Hop Multi-Path Hierarchical), SEP (Stable Election Protocol for clustered heterogeneous WSN), and TEEN (Threshold-sensitive Energy Efficient Network).

Figure 6 presents the individual clusters formed when using the four routing protocols. In the figures, the sign "o" indicates the active nodes in the network; the sign "*" indicates the heads of each cluster; and the sign "." indicates the inactive clusters.

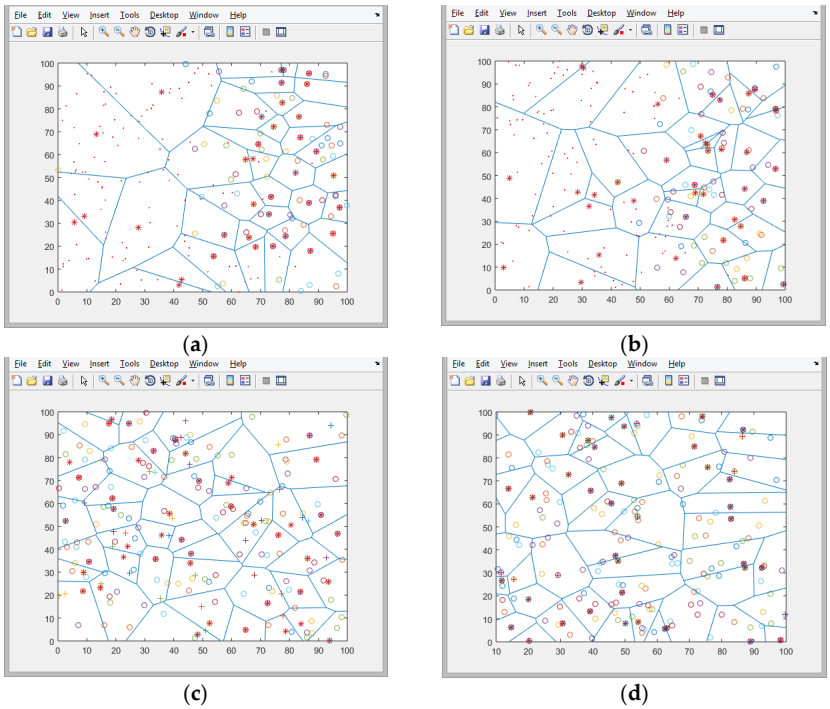


Figure 6. Clustering of individual protocols: (**a**) EAMMH; (**b**) LEACH; (**c**) SEP; and (**d**) TEEN.

An experimental study was conducted on the number of inactive nodes at each node traversal in the network. This criterion compares the quality of network utilization for different routing protocols. The comparison was made at 25, 50, 75, and 100 iterations of traversal of the nodes in the network.

In Figure 7, the graphs for the four routing protocols for 100 iterations of traversal of the network are presented.

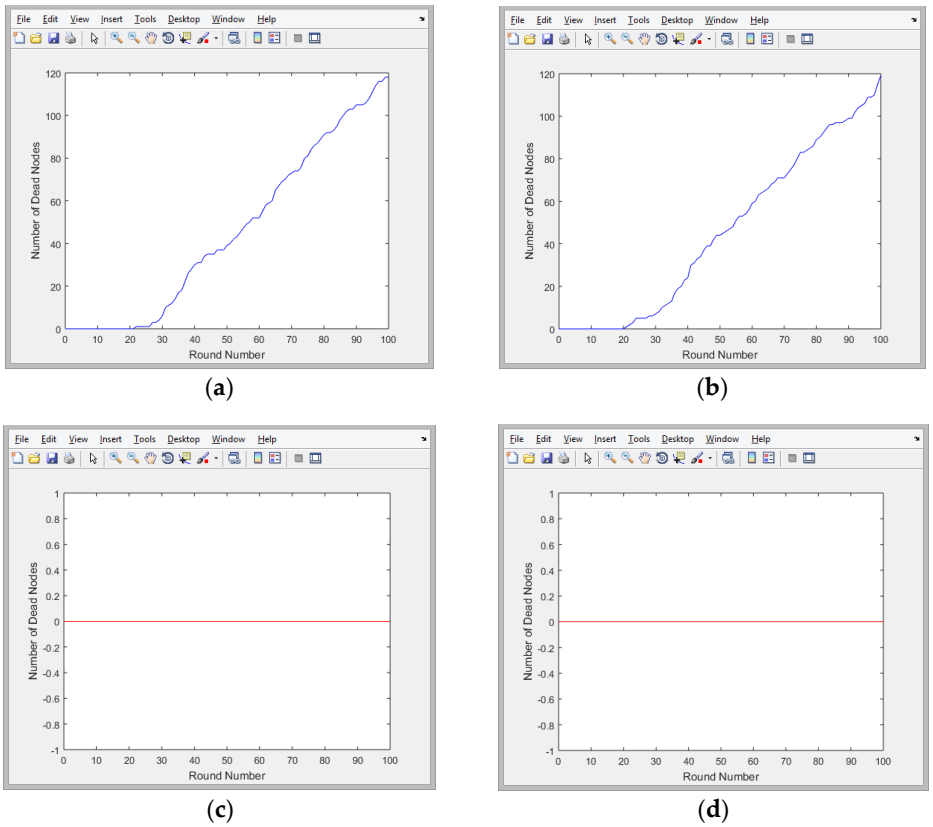


Figure 7. Number of inactive nodes in 100 iterations of traversing the nodes in the network: (**a**) EAMMH; (**b**) LEACH; (**c**) SEP; and (**d**) TEEN.

The obtained results show that the SEP and TEEN routing protocols have better performance and efficiency with respect to inactive nodes in the network compared to the other two protocols.

An experimental study was also conducted on the average energy of each node during each round of network traversal. This criterion shows the results of the average energy of each node during each round of network traversal.

Figure 8 presents the results for 100 iterations of network traversal for the four routing protocols.

The results obtained show that the average energy of each node in the network decreases with an increasing number of iterations.

With fewer iterations, the energy change curve is linear. With increasing iterations, the shape of the curve changes to parabolic.

The smallest average energy of each node in the network is when using the EAMMH and LEACH routing protocols.

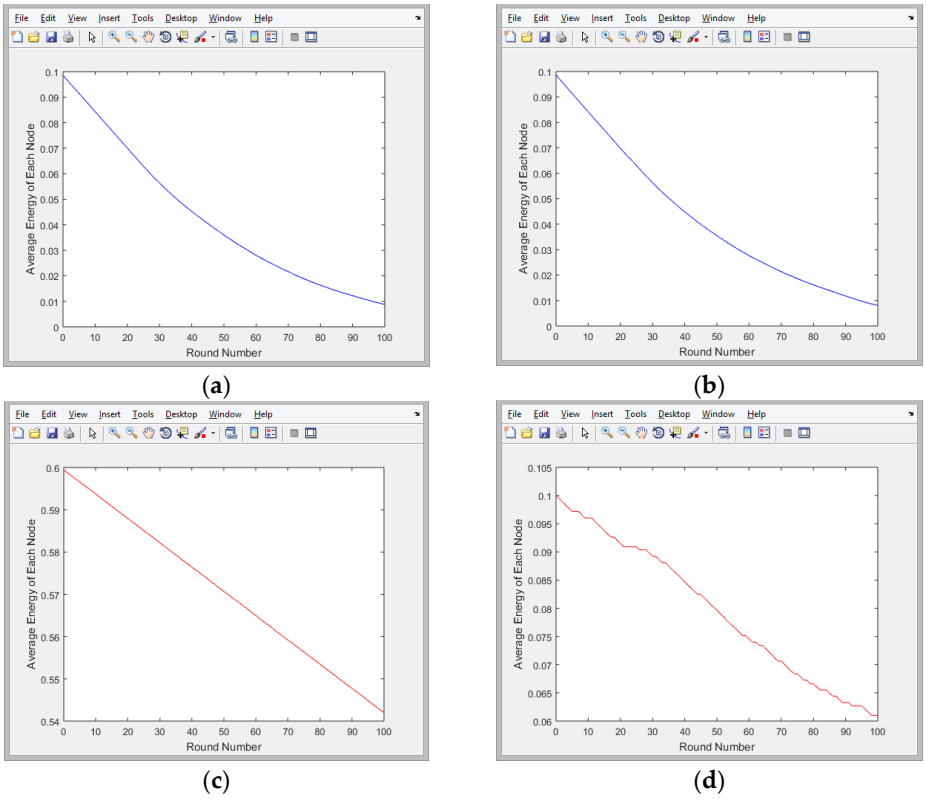


Figure 8. Average energy of each node in the network over 100 iterations of traversing the nodes in the network: (**a**) EAMMH; (**b**) LEACH; (**c**) SEP; and (**d**) TEEN.

3. Conclusions

For the simulation study of protocols for transmitting data from measurements of basic soil parameters, program modules have been developed in the MATLAB environment, which allow the necessary parameters for studying protocols in wireless networks to be set with respect to several basic criteria.

This comparison provides an opportunity to study the life of sensors in the network and the energy consumption of different routing techniques.

The results obtained show that the SEP and TEEN routing protocols have better performance and efficiency with respect to inactive nodes in the network compared to the other two protocols.

The EAMMH and LEACH routing protocols are the best in terms of the energy consumption by sensors in the network.

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