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Designing an Energy-Efficient Mechanism to Regulate the Transmission Power Rate in Wireless Sensor Networks

Rahim Mehri [1]*, Abbas Mirzaei Somarin [2]

[1] M.Sc, Software Engineering, Islamic Azad University of Germi Branch, Germi, Iran.
[2] Ph.D, Software Engineering, Islamic Azad University of Ardabil Branch, Ardabil, Iran.

ABSTRACT

Wireless sensor networks (WSNs) are of great importance for wireless technology. While wireless sensor networks have many advantages, they also have some drawbacks such as limited sending ability of nodes, because replaing or charging battery of sensor is impossible during its lifetime. Sending data at high power levels reduces operating power and increases energy consumption. On the other hand, sending data at low powers may lead to data loss, delay and interference. Data communication is the operation that consumes the most power. Much of the researches on wireless sensor network have focused on creating routing methods that are energy-efficient, while in addition to optimizing routing, transmission power regulation is also important. Therefore, there is a need to strategies for managing node transmission power. This paper presents an Energy-Aware routing algorithm with Transmission Power control (EATPC) for wireless sensor networks. The proposed EATPC method selects the best routes and, after adjusting the transmission power, data is transmitted from the source to the sink using measures such as average energy consumption, overhead control and step count calculation. The proposed EATPC method has been evaluated using 2NS-simulator and compared with RPAR method. The evaluation results show the efficiency of the EATPC method in terms of operating power, residual energy in the sensor node and network lifetime.

Keywords: *Wireless Sensor Network, Transmission Power Regulation, Network Lifetime, Residual Energy, EATPC Proposed Method.*

Corresponding author: Rahim Mehri
e-mail ✉ r64.mehri @ gmail.com
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1. INTRODUCTION

Today, transmission rate regulation is one of the most challenging topics in the field of electronics and computer science. Having knowledge about the changes in the evironment or the condition of any set, we need a set of equipment known as sensors, which provide the desired changes (physical or chemical changes) in the form of a response to measure the extent or presence of changes. Sensors that are attached to devices and structures or placed in the environment are able to collect valuable information and have many benefits for society. The range of sensor wireless networks applications is very wide and includes agricultural, medical and industrial applications to military and nuclear applications and traffic control and meteorology and home or workplace automation.

A wireless sensor network is a set of sensors combined with a physical environment. Sensors are in small size and able to sense and process physical phenomena (Alzaid et al., 2013).

The ideal wireless sensor network should consume little energy, have intelligently programmed, be able to receive data quickly and accurately over a long period of time, inexpensive installing, and require no maintenance.

The use of such sensors can be done along with the correct knowledge about the use of these sensors and good Miniaturization and reduced cost realize that recent and future goals are in the development of the MEMS and NEMS understanding of the problem. The battery lifetime used in these sensors as well as the rate of sensor updates and their size are among the major design considerations in this area.

These networks are networks containing independent sensors in the environment that measure physical or environmental conditions such as temperature, sound, vibration, pressure, movement or pollution at various locations. These sensors are small and work in interaction with each other and have a limited amount of stored energy, memory and bandwidth. These sensors or tools are called nodes. Limitations such as buffer memory, limited computations, and battery power made to various methods introduced for routing and transmitting data. As mentioned, the energy of the sensors is limited and their power supplies can not be replaced or recharged, so reduction of power consumption is the most important issue in wireless sensor networks.

One of the new solutions proposed for this purpose is the interlayer solution. In this solution, interactions between adjacent or non-adjacent layers are used in order for better working. Some challenges have an interlayer nature; ie, they are not solvable in a single layer and require multi-layered cooperation. (Sohraby et al., 2007) The aim of this study is introduce a new method for transmission power regulation in wireless sensor networks that save energy and improve the performance of wireless sensor networks.

One of the main issues in the sensor network is how to choose low-cost sensors with small receiver nodes. Considering these goals, the receiving nodes are now essentially prototypes. disciplines, and a number of low-receiver nodes are presented, and a number of nodes are still under research. There is an overview about network usage, databases, and related components and topics of SNM.

The popularity of mobile wireless sensor networks has increased dramatically due to their ability to connect the physical world to the virtual world. In mobile sensor networks, sensor nodes move freely in the area without the need for any special infrastructure. Mobile sensor networks due to unique challenges in areas such as resource management, coverage, routing protocol and security have been increasingly concerned in many applications such as target tracking in military applications, disaster detection, climate monitoring, health applications, etc. In these networks, the routing process in mobile sensor networks has become much more difficult due to the mobility of the nodes, where the communications in the network may change dynamically.

One of the most important goals in designing wireless sensor networks is to extend the lifetime of each sensor node and thus the network lifetime. But the problem is the limitation of transmission power nodes, because it is impractical to replace or charge the battery of a sensor during its lifetime. Data transmission at high power levels reduces operating power and increases energy consumption. On the other hand, data transmission at low power may result in data loss, delay and interference. Data communication is one of the operation that consumes the most power. So we need strategies to control the ability to send nodes.

Many methods have been introduced to improve wireless sensor networks, each one has somehow emphasized the improvement of one or more measures of these networks. Some authors have used clustering and different cluster selection methods, and others have chosen the the existing algorithms and their combination with these networks.

In LMN and LMA algorithms, a node determines its confine by counting the number of nodes that have confirmed its lighthouse message. Two local or distributed algorithms are proposed for fixed and stationary wireless sensor networks. The basic assumption is that each sensor uses the same transmission power to send packets to all its neighbors. The algorithms are designed to be combined with routing protocols that can obtain some useful information about the power level of each node. In this method, the power regulation mechanisms are similar to the LMA method, so the transmitter knows how to connect its neighbors to other nodes. Each sensor does not store its neighbors table, as this method adjusts the transmission power based on the number of available neighbors. Therefore, less resources are needed, but is still in the early stages of development. (Boubiche et al., 2015)

In the PCBL algorithm, each sensor node regulates the radio transmission power for each destination node to the smallest possible value, so that. Threshold PRR <PRR. Also filters nodes with a much lower PRR value. According to the proposed algorithm, each node measures the quality of each link by determining PRR at different levels of submission power at first. In order to determine the reliability of the required link, we need to set a threshold value, and to do this, an optimal single transmission power is requlated for each link. If the PRR is greater than the threshold, the threshold will be at least the observed PRR value. Otherwise, it will be maximum transmission power. The other threshold is the blacklist threshold, which is set according to whether a link can be turned into a good one. If a link fails to become a good link, it will be blacklisted and will no longer be used. The disadvantage of this method is that they are designed to run with diffuse routing protocols and no experiments have been performed on them with other protocols. (Tan et al., 2009)

In another study in 2012, transmission power control is studied based on Binary Search, where TPC-BS consists of two phases. The first phase is when the node sends data for the first time. At this time, a test packet is sent using the binary search method to find a suitable transmision power. The second phase is a process that dynamically responds to changes in the radio frequency conditions of a sensor network, such as node displacement or changes in weather conditions that occur for a variety of reasons. When a data packet with a certain transmission power is sent, the receiver node sends a packet, where it attaches the node and the length of the received signal, creating the ACK response packet. When the node transmitter receives the ACK response packet, it calculates the distance between the nodes using the received coordination point and also determines the shortest path, and then optimizes the transmitted RF power level using the threshold value and the shortest path value. In this method, the additional overhead is minimized by optimizing the number of test packets that are sent to find the right amount of power with the binary search scheme (OH, 2012).

Recent advances in electronics caused to integrate sensors and their transmitters as well as electronic components into an integrated IC circuit (Ilyas and Mahgoub, 2004). That is why today integrated circuits containing these sensors and their accessories are available at a low price and have made it possible to install them based on their existing protocols. The most important in these networks is optimal routing to reduce energy consumption and increase network efficiency. This study aims to to present a new method for regulating the transmission power rate in wireless sensor networks to save energy and improve the efficiency of wireless sensor networks.

Todays, sensor networks are one of the novel scientific topics and a lot of research is done on improving the performance of these networks. So far, a lot of work has been done to improve and increase the efficiency of information transmission in sensor networks. One of the methods in this field is the use of new algorithms. In this study, a new routing clustering based algorithm that uses the selection of appropriate headers in terms of energy and regulation of transmitted power causes the efficiency of wireless sensor networks in terms of energy consumption and network life is used to improve the sensor network. First, the wireless sensor networks are examined, then in the proposed method, the headers are selected based on important criteria of sensor networks such as energy and overhead control, and then the appropriate paths of the transmission power adjusted based on the received signal power is used and then the data is sent.

2. PROPOSED METHOD

In this study, we present an Energy Aware with Transmisson Power control (EATPC) for wireless sensor networks. The proposed EATPC method selects the best routes and, after adjusting the transmitted power, transmits the data packets from the source to the sink using criteria such as average power consumption, overhead control, and hop count.

Energy Aware with Transmit Power control (EATPC)

In mobile sensor networks, the main inefficiency of current protocols is being single-purpose. They are all provided with a solution rather than a set of solutions. To select any routing protocol for each application, decision makers tend to have sets of solutions with multiple goals. In most mobile sensor networks, sensor nodes are equipped with GPS, so the cost of such networks is high. Our proposed method (EATPC) provides a hybrid solution under node mobility routing, this method does not require the sensor nodes to be equipped with GPS, so the cost of the network is limited. The proposed EATPC method is an adaptive clustering method that regulates the transmitted power and then uses the measured average of many criteria, which are important parameters of systems in mobile sensor networks. The criteria used are:

- **Average Energy Consumption (En):** This indicates the ratio of the total energy used per node to the number of events detected.
- **Calculate the number of hops (H):** Defined as the number of hops from the source node to the destination node.
- **Overhead control:** This ratio indicates control messages to data transmission messages.

These criteria have been used to select the header and these criteria are used to select the appropriate route. The main goal of the proposed EATPC method is to reduce the power consumption of all nodes, which automatically leads to an increase in system life.

Hypotheses of the Proposed Method

In the proposed EATPC method, all nodes are homogeneous and have the same energy. All nodes are randomly distributed. Sink and header (CH) are fixed. Only a limited number of nodes are moving in the target area. Moving nodes are responsible for measuring events around them. The whole sensing area is divided into small clusters. Each cluster has a leader called header (CH). Except for the CH header, the other nodes are members of the cluster. The cluster is selected by the member nodes and the member nodes of each cluster communicate only with their associated CH. They do not communicate with other nodes in their cluster or other nodes in the cluster. Cluster member nodes never communicate directly with other cluster headers. The base station (BS) is a high-energy node located away from the sensing area. BS can communicate directly with any CH header or cluster member node.

Network model in the proposed EATPC method

Figure 1 shows that the network model for the proposed method consists of a number of sensor nodes and a sink node. In the first level, the nodes within the clusters are arranged in the binary hip tree based on the weighted average of the criteria mentioned in the previous section. The nodes within each cluster are arranged in such a way that for all nodes the measured sum is greater than or equal to all their offspring. The node with the largest weighted sum of the criteria stated will be selected as the CH of that cluster. In the second level of the binary hip tree, all CHs are arranged from different clusters in the tree. The node with the largest weighted sum of the criteria expressed will be selected as the header of all headers. The selected header will send the data to the base station. The role of the header among the different nodes is based on the measured sum of three criteria, and these criteria cause the selection of the header to circulate among the nodes and not to select a specific node as the header. The header circuit may balance the energy consumption of all nodes.

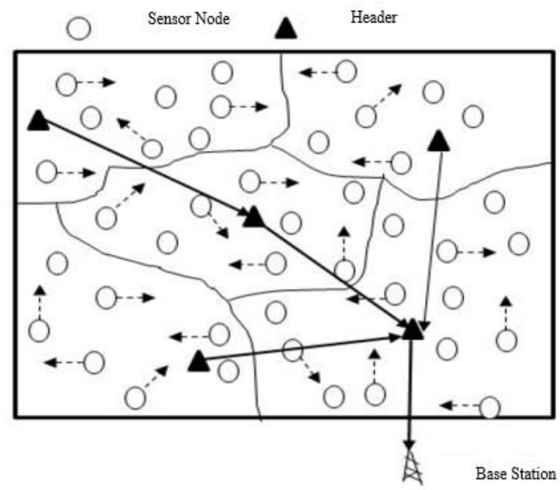


Figure 1: Clustering model in the proposed EATPC method

Routing in the proposed EATPC method

The proposed EATPC method can continuously evaluate different rouths and select the best routh to send data to the sink. The proposed EATPC method has the following steps:

- **Cluster Setting:** This step is for when the routing table is created on each sensor node.
- **Data connection:** Data will be sent from a source to the sink when the routes are selected according to the evaluated average of the stated criteria.
- **Transmission power setting:** This step is to adjust the power transmitted from each node to another so that the transmitted packet is not lost.

Clusterring step

This step itself consists of the following steps:

1. Nodes arrange themselves in the form of local clusters.
2. The selection of the header is non-periodic and is done whenever the network topology changes.
3. The proposed method is based on the measured average, combining different criteria and adjusting the transmitted power.
4. The selection of the CH header is calculated based on the three parameters expressed according to the study of Mr. Kulkarni through the formula 4-1:

$$f(n_{ij}) = \alpha . m_{energy}(n_{ij}) + (1-\alpha) . \left[\beta . m_{overhead}(n_{ij}) + (1-\beta)\left[\gamma . m_{hops}(n_{ij})\right]\right] \quad (1)$$

The parameters 0≤α,β, γ≤ 1 are the measurement factors for the relevant system parameters that are selected according to the study of Mr. Kulkarni.

5. For each n_i node, we evaluate the value of the cost function through the parameters {energy, overhead control and number of steps}. $Cost_{min}$ means the minimum amount of parameter measurement. The cost function is evaluated through a function such as the example given in Formula 2:

$$m_{cost}(n_i) = \begin{cases} cost_{\min} & if\ i=1 \\ \max\{cost(n_i), \min\{m_{cost}(n_{ij})|n_{ij} \in \text{U}_i\}, if\ i\ \neq 1\} \end{cases} \quad (2)$$

Where i = 1 represents the sink node.

6. For node i-th, this information is listed in a table called n_i node routing table.

$$Table\ _i = \{(n_{ij}, m(n_{ij})|n_{ij} \in \text{U}_i\} \quad (3)$$

The value of the function $m(n_{ij})$ is obtained through three expressed criteria of energy (E), overhead control and number of Hopes (H).

$$m(n_{ij}) = \begin{pmatrix} m_{E(n_{ij})}, m_{overhead(n_{ij})}, \\ m_{H(n_{ij})} \end{pmatrix} \quad (4)$$

Each node maintains the values of these parameters in its routing table and updates them regularly to optimize the path to the sink node.

7. All n_i neighboring nodes update their routing tables.

8. When, the routing table is updated, the i-node sends its measured information only to its neighbors using Formula 5.

$$m(n_i) = \begin{pmatrix} m_{E(n_i)}, m_{overhead(n_i)}, \\ m_{H(n_i)} \end{pmatrix} \quad (5)$$

9. All clusters' nodes are arranged in such a way that, for all of them, the weighted sum of the measured parameters is greater or equal than all offspring.

10. The node with the largest sum of measured parameters in level one will be selected as the header.

11. In level 2, all the branches in level one communicate as a binary hip tree. On the other hand, all sensor nodes establish the connection path between the root node of the binary hip tree and the sink node.

Data Connection Stage

1. The source node sends small packets of data to its parent node in the tree and receives the confirmation response and then adjusts the transmission power according, where the data surely is received by the recipient. Information is available in the submission table.

2. The parent node sends the data packet through a binary tree to its parent node according to the previous step and this process continues.

3. This process continues until the data packet reaches the sink node.

Transmitted Power Regulation

In the proposed method, the transmitted power control mechanism is also adopted in the proposed method in order to minimize energy consumption,

In the proposed EATPC algorithm, a confirmation message is received from the receiving node when each packet is sent by the node. When the received node sends its received signal strength (RSSI) along with sending a confirmation message. In the proposed method, first through formula (6), the sender can find the amount of packet energy reduction in this link.

$$p_l = p_s - p_r \quad (6)$$

In formula 4-6, p_l stands for energy reduction; p_s indicates the transmission power; p_r stands for received power.

If the received power (p_r) is greater than $p_{\max T}$ (greater than the maximum threshold) or p_r is less than $p_{\max T}$ (less than the minimum threshold), the sending node of the transmitted power ($p_{new\ s}$) adapts to formula (7).

$$p_{new\ s} = \frac{p_{\max T} + p_{\min T}}{2} + p_l \quad (7)$$

In the proposed EATPC method, the maximum power sent by the node is used while the beginning of the data transmission, the sending node regulates the transmitted power according to the received confirmation message. If the sent node fails to receive the confirmation message, it will resend the packet 10 times the power, and if it does not receive a maximum response this time, it will make sure that the sent packet has failed.

The packet receiving node also regulates the confirmation message as same as the optimization. If the received node receives a packet with the same serial number as before, then it will increase the power of the confirmation message to reach the sender.

Evaluation Criteria

Throughput: This criterion is obtained by dividing the amount of data received at the destination by the time of data delivery. Measures such as packet delivery rate and end-to-end latency are also involved in the throughput. The throughput of the network is higher, if these criteria be better.

Throughput = (received bytes ∗ 8) / (simulation time ∗ 1024 ∗ 1024) (8)

Residual Energy for Sensor Nodes: The amount of energy is of great importance in wireless sensor networks due to limited resources such as power, energy, bandwidth, processing capacity and storage space in the nodes, redued routing overhead and ensuring high packet delivery rate. The measure of the residual energy for the sensor nodes indicates the amount of energy left for the sensor nodes after routing.

Network lifetime: The length of time a network is stable and can send data packets.

Simulation Environment and Scenario Designing

Based on the necessary research and review of numerous articles on simulation software, the best simulator for wireless sensor networks is NS-2 simulator for flexibility and software performance, which is a very powerful simulator for the network. This simulator uses C ++ code to simulate. Using this type of simulator, various methods can be implemented and simulated and network performance can be observed. We also used the NS-2 emulator for simulation. The values of the parameters used in the simulation are given in Table 1.

Table 1: Simulation parameters

Kind of Simulation	NS2 2.34
*10001000	Environment
50-250	Number of Sensor Nodes
250 Meters	Transmission Area
Omenia Antenna	Kind of Antenna
20-100	Simulation Time
802_11	MAC Layer
CBR (UDP)	Kind of Traffic
150 Packest	Buffer Size
Random	Node Location
EATPC & RPAR	Protocols

A number of parameters including the simulation time can be changed over simulation, and the simulation results can be evaluated. We have considered the number of nodes in the network in several scenarios equal to 50, 100, 150, 200 and 250 nodes. The simulation environment used in this scenario is for 1000 m by 1000 m simulation. The radio propagation amplitude is 250 for each node, its MAC layer protocol is IEEE 802.11. In this simulation, there are also two traffic flows in the network that send the package to the network at a fixed rate. We performed the simulation in two scenarios, one at different times and the other at different number of sensor nodes. In this scenario, we have considered the simulation time to be 20 to 100 seconds, and once we considered this simulation on our proposed method (EATPC) and again compared it with the RPAR method. The buffer size used in this scenario is 150 packets. The position of the nodes in this scenario is random.

3. RESULTS

The simulation was performed on the proposed method and it was ensured that the proposed EATPC method works properly. The simulation results showed that EATPC has better performance in throughput, residual energy for sensor nodes, and network lifetime.

Throughput

Throughput is one of the most important and basic criteria in sensor networks. Therefore, this criterion was examined to evaluate the proposed method.

Figure 2 shows that the throughput for EATPC is significantly lower compared to RPAR. This figure shows that the proposed EATPC method has better performance when the number of sensor nodes is different. That's whay in the proposed method for header selection, the header note containing best measures such as average consumption energy, overhead control and hop number count is selected. Also, by adjusting the transmission power in the proposed method, the sending packages surely reach the destination and a smaller number of packages will be lost. Therefore, the proposed method has a higher throughput compared to the RPAR method.

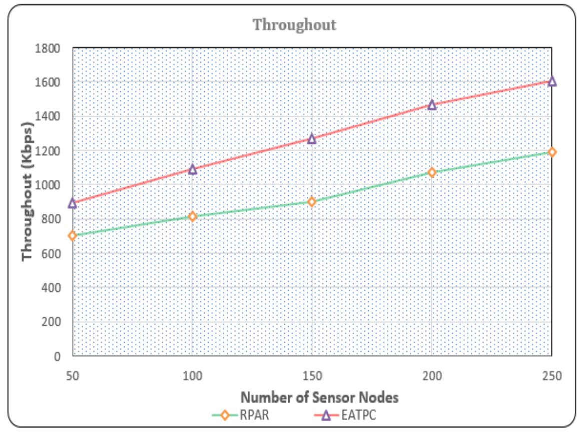
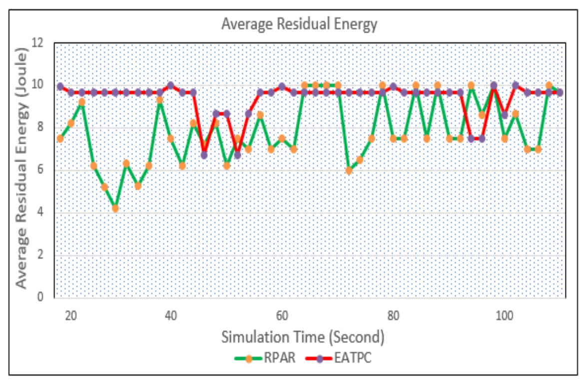


Figure 2: Throughout of Residual energy in the sensor nodes

One of the main issues in wireless sensor networks and has been noted in this study too, is the residual energy in the node, which will directly affect the lifetime of the network. As shown in Figures 3a and B, the amount of energy consumed in the proposed method (EATPC) is higher than the RPAR method. That's why less energy is consumed for regulation transmission power. Also, residual energy is considered, when the header is slecting and the header with highest energy is selectd. This causes energy control in the network and increases the residual energy, and in this case, the proposed method has better performance.



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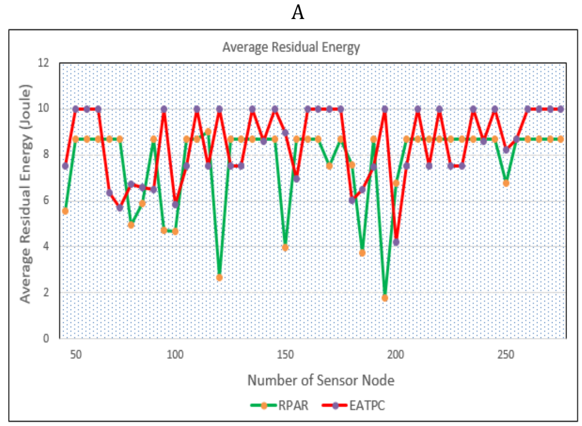
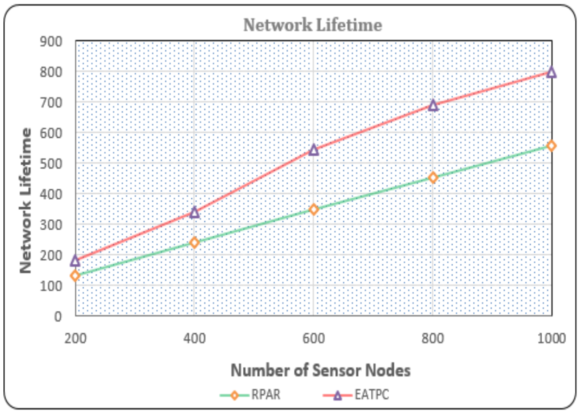


B

Figure 3: a) The amount of Residual Energy in the sensor nodes in the time scenario, b) The amount of Residual Energy in the sensor nodes in the sensor node number scenario

Network lifetime

As mentioned, the amount of residual energy in the sensor nodes directly affects the network lifetime. As shown in Figures 4a and B, the proposed EATPC method works better than the RPAR method for the network lifetime criterion. In the EATPC algorithm, the sensor node can set the best transmission power. In addition, by selecting the headers with the highest residual energy, low overhead and fewer hops have increased the network life.



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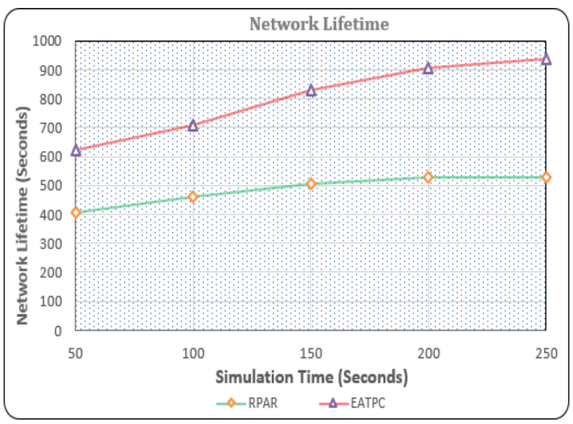

B

Figure 4: a) Network lifetime at time scenario, b) Network lifetime in the sensor node number scenario

4. CONCLUSION

In a wireless sensor network (WSN), sensor nodes collect data regarding measurement, computation, and communication functions. Sensor nodes usually have limited battery resources, so are distributed in inaccessible areas, depending on the application and the type of central station, and therefore must operate at a specified time without recharging the battery and relocating. One of the most important goals in designing wireless sensor networks is to extend the lifetime of each sensor node and thus the network life. But the problem is confined power to send nodes, because it is impractical to replace or charge the battery of a sensor during its lifetime. Sending data at high power levels reduces operating power and increases energy consumption. On the other hand, sending data at low powers may lead to data loss or delay and interference.

In this study, the EATPC method is presented. This method selects the best header with appropriate clustering based on criteria such as average energy consumption, overhead control and hop count, then selects the best routes for data transfer. In the proposed EATPC method after regulationg the transmission power, data packets is transmitted from the source to the sink.

To evaluate our proposed method, we tested this method using 2NS-simulator. We compared the proposed EATPC method in terms of operating power, network lifetime and, most importantly, optimized network energy consumption with the RPAR method. Our proposed method showed better performance in all the measures compared to RPAR.

According to the results, the proposed method has shown good performance. To improve performance, a program can be proposed in the future to combine the proposed EATPC algorithm with other algorithms to further enhance the improvement. metaheuristic algorithms is a good case. Metaheuristic algorithms have increased efficiency in many cases, so in this method it is possible to increase productivity by using these methods.

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