Power Consumption Efficient Routing Protocol for Forest Fire Detection based on Mobile Sensor Networks

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***Abstract*— Wireless sensor networks play an important role in many applications that require networks that could be used in emergency and rescue operations or in disasters such as forest fire. Forest fires are costing millions of dollars in addition to the big losses of trees and air pollution that is spreading to the neighbouring countries. In such disaster, an effective and reliable routing protocol in terms of energy consumption is much needed for continuous monitoring. This paper presents a new routing protocol named Power Consumption Efficient-Optimized Link State Routing (PCE-OLSR) protocol in the forest fire detection. PCE-OLSR protocol exploits the energy of the nodes that is located in the fire zone in order to fully utilize its energy and consequently preserved the energy of other nodes in the network. The proposed PCE-OLSR protocol has been evaluated and compared with the traditional OLSR protocol in terms of packet delivery ratio, end to end delay, energy consumption and routing overhead. Results have shown that PCE-OLSR performs better than its comparative.**

Keywords*— *Forest fire detection, OLSR, routing protocol, mobile sensor network, MANET.

I. INTRODUCTION

The advance technologies of networking allowed users to wirelessly communicate through an infrastructure-less network known as Mobile Ad Hoc Network (MANET) which is composed of many mobile devices. Fig. 1 illustrates the MANET technology that is equipped with a set of wireless mobile nodes which move independently in any direction and location [1]. Mobile sensor network is a subset of MANET where in this network, the node in this network is typically smaller in size, and consists of a microcontroller, various sensors such as temperature, humidity and pressure, radio transceiver, and powered by battery.

Nodes in sensor network cooperate with each other in order to reach destination node, since each node in the network is able to communicate only with those nodes located within its transmission radius R, while the source and destination nodes can be located at a distance much higher than R. All the nodes in a multi-hop wireless ad hoc network cooperate with each other to form a network without the presence of any infrastructure such as access point or base station [2]. In this type of network, mobile nodes are required to forward packets for each other to enable communication with nodes outside the transmission range. Routing protocols are available in mobile sensor networks which specify the route and deliver packets from the source to the destination. Different routing protocols have been proposed for mobile sensor networks based on different criteria and applications to improve the network performance appropriately for the desired environments [3].

Mobile sensor network plays an important role in many applications that require wireless networks that could be used in emergency and rescue operations or in the disasters, such as forest fire, flood, volcano outbreaks, and earthquake. Forest fires are among the terrible disasters that impose threats to forest resources and human life [4]. This disaster is the most serious environmental problem facing the world, where this fire is characterized as vast spreading of fire at large distances. Forest fires if continued for months, can result in many environmental risks. There are many researchers and developers who have proposed different routing protocols with respect to the forest fire detection application. In [5], the authors have presented a fire detection system in indoor environment and forest by utilizing wireless sensor network. In both scenarios, web-based application is used. Therefore, the fire is detected remotely without the need for being present in the danger location by using the web network and mobile platform. However, the network performance has not been evaluated in terms of energy conservation and hence the network lifetime is unknown.

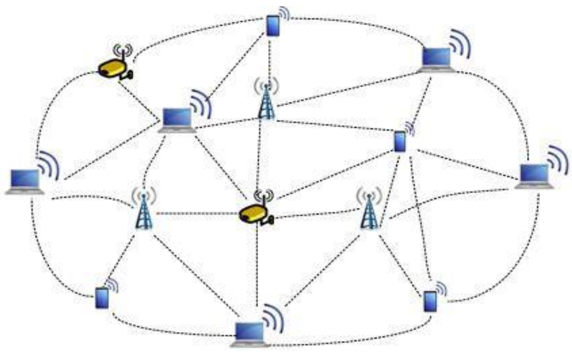

Fig. 1. MANET Technology

A group of researchers in [6] have proposed a new monitoring system for forest fire detection to reduce the dropped rate of data that have a high priority to detect the fire. This is done through specifying the data that has a high priority directly after detecting the fire and just before incidents that caused by the fire. The proposed method has been compared with [7] and it is shown that the method can reduce the loss of data with high priority. Moreover, the node only sends the data that has a high priority to the node which has a low probability of destruction caused by the fire to decrease end-to-end delay. This method also has a lesser effect of the wind as compared with the conventional method.

The study in [8] has presented a performance comparison of three routing protocols namely DSDV (Destination Sequence-Distance Vector), Dynamic Source Routing (DSR), and AODV(Ad-hoc on demand distance vector) in the forest fire detection and the performance metrics that are used in this comparison are energy consumption, packet delivery ratio, and average end-to-end delay. The results have shown that AODV routing protocol is better than DSR and DSDV in terms of packet delivery ratio and also has the lowest average end-to-end delay. For energy consumption, DSDV is the best, where this protocol has a lower value than AODV and DSR. However, AODV has the highest value in energy consumption.

The authors in [9] have presented a comparative study of two methods namely Korean and Canadian, and compared their performance in the forest fire detection in terms of execution speed and energy consumption. In the Canadian method, the account of the fire index depends on FWI (Fire Weather Index). This means that not all data from the sensors are transmitted to the sink and only a few of aggregated index are sent. Consequently, it decreases the energy consumption as not all sensors need to transmit in long distance. This approach relies on identifying the daily weather in the daytime depending on speed wind, humidity, temperature and rain for 24 hours. Meanwhile, the Korean method is executed based on the system FFSS (Forest-fires Surveillance System) that is developed in [10]. In this study, the middleware processes and receives packets from the transceiver and shows its results. It is proved the Canadian method is better than the Korean method to detect fire in terms of execution speed and energy consumption.

The authors in [11] have proposed an efficient framework for monitoring and detecting the forest fire via wireless sensor network in square grid and hexagonal grid. The design in this framework requires three main parts, they are in-cluster communication protocol, network architecture and sensor deployment. The framework provides a fast response to forest fires and increases the lifetime of the sensors. Moreover, it provides an overall analysis that covers all aspects of the life cycle of sensor network, especially in the forest fire. The algorithm implemented has many characteristics: effective power administration, effective management of wake and sleep cycles, and can increase data flow. In their proposed work, the square grid requires nodes less than the hexagonal and the overlapping in the hexagonal grid is more than the square grid, thus, the performance of the square grid is better than hexagonal.

The research paper in [12] has proposed a comprehensive framework to detect and monitor the fire in the forest by using wireless sensor networks and FireLib simulator. This framework includes the architecture of the wireless sensor network, efficiency of the energy that consumed by the sensor nodes, communication and clustering protocols, detecting the fire as soon as possible, create the network structure depending on the different environmental conditions and forecasting the speed and the spread direction of the fire in the forest. In the proposed approach, sensor nodes are deployed in a way to reduce the probability of collisions of the packets. The distances among the sensor nodes must be similar for all nodes, thus, the nodes will consume almost the same value of the energy. Due to the importance of protecting this area, the network must cover all the area with a low number of nodes.

The authors in [13] have presented a comparison study between Location Aided Routing (LAR) and Optimized Link State Routing (OLSR) routing protocols in the forest fire detection. These protocols are evaluated in terms of packet delivery ratio, end-to-end delay, energy consumption and overload. The results have shown that the performance of LAR has outperformed OLSR protocol in terms of packet delivery ratio, routing overhead and energy consumption. However, OLSR protocol has lower end to end delay than LAR.

It is worth mentioning that there are some studies which have addressed nodes movements' mechanisms that can be considered in our study in terms of nodes deployment in the forest environment. Examples of these studies such as sensor nodes provided with wheels which have ability to move to the risk zone [14], simulation of the robot activities in the forest environment [15], and drones [16].

II. Review of Optimized Link State Routing Protocol (OLSR)

OLSR is considered as one of the proactive routing protocols due to its proactive nature, where each node has a routing table with nodes information such as node location. Each node updates its routing table by exchanging messages with other nodes periodically [17]. These messages are called Hello Message (HM) and Topology Control (TC). However, this process of exchanging messages leads to a huge overhead in the network. Therefore, the OLSR protocol uses Multi-Point Relays (MPRs) which is used to forward those messages and also to reduce the size of the control message. The set of MPRs is determined for all nodes located at 2-hops away. Nevertheless, if the route in the OLSR protocol has a damaged link or a broken link, it will not identify the source node immediately. The source node finds the information route to the destination node from the intermediate nodes when they are sending their next data packet.

The OLSR routing protocol is not efficient in terms of energy consumption, reliability, and packet delivery ratio when applied in forest fire detection scenarios. Therefore, such protocol needs improvement to mitigate its shortcomings. Thus, in this paper, OLSR protocol is evaluated and results are analyzed and compared with our proposed PCE-OLSR (Power consumption efficient – OLSR) protocol to ascertain of PCE-OLSR optimality and validity to function well under fire scenario for forest detection.

III. THE PROPOSED POWER CONSUMPTION EFFICIENT-OLSR (PCE-OLSR) PROTOCOL

We propose an improved OLSR protocol focusing on specific scenario which is monitoring of fire in the forest. The new routing protocol is called Power Consumption Efficient-OLSR (PCE-OLSR). It is assumed that every node is provided with a temperature sensor to sense the data continuously since the forest fire detection scenario has been chosen as a critical application in this work. PCE-OLSR considers the node health which is temperature as one of the most important routing criteria when transmitting packets from source node to destination node in the forest fire environment. PCE-OLSR protocol always aims to use nodes which are located in the danger zones to fully use their energy before they are destroyed and burnt in the fire. On the other hand, the energy of other nodes in the safe areas can be conserved to ensure that they keep functioning for as long as possible. Thus, the lifetime of the network can be prolonged for much longer in order to monitor the forest even when the fire has ended. Also, the network may then stay available to detect fire if it happens again.

Besides this, PCE-OLSR has another criterion which is route length where a node that sends the packet will use the shortest route to the sink node to ensure that packets are forwarded to the destination node with a minimum cost of energy. This is very important to save more energy in the network lifetime and avoid wasting energy by choosing routes that need additional energy to deliver packets to the destination node. Based on these two criteria for routing packets, PCE-OLSR is able to forward packets through the most appropriate routes in the forest fires. PCE-OLSR has a routing management module that plays an essential role in terms of updating the forwarding choices and also making forwarding decisions. The decision to forward the packet to the appropriate neighbour nodes is based on two routing factors which are the total cost of the path and the node temperature. Meanwhile the updating process is to update the status of the neighbours and also sending the TC messages in order to inform neighbours if any critical event is identified. PCE-OLSR has a neighbourhood management module that aims to identify neighbour nodes via Hello messages and also to update the routing table as a natural work of proactive routing protocols. This module is very necessary at the beginning stage. Initially when the network is setup, the discovery process begins where nodes will start sending Hello messages to neighbouring nodes. When the neighbouring nodes receive Hello messages, they will send back replies. After that, the neighbourhood management module will record the new neighbour in the routing table.

In PCE-OLSR, a mechanism to select the best parent is designed where the protocol must choose the node that has the least cost to the destination node in order to avoid energy being wasted in needless transmissions. Furthermore, the node that is going to be selected must be located in a danger zone (fire area) in order to totally use its energy before it is burnt and destroyed in the fire. Thus, the highest priority is given to the nodes that have the shortest route to the destination node and located in danger areas. The proposed PCE-OLSR presents a mechanism to manage the fire's threat on each sensor node in the network. Each node in the network has different threat levels that is classified based on certain scenarios as shown in Table 1. The proposed PCE-OLSR has a threshold of detecting a fire which is set at 60 degrees Celsius. Therefore, a fire is detected once the node's temperature sensor reached this value. This threshold value is set in order to avoid false alarm from the sensor node.

TABLE I. NODE LEVELS IN THE FOREST FIRE DETECTION

Node status	Description
SAFE	The beginning stage and there is no forest fires
LESS SAFE	One-hop away from the node that has detected fire
UNSAFE	The Node has detected a forest fire
FAILED	The Node has burnt and destroyed

Fig. 2 shows the PCE-OLSR operation at different scenarios. As shown in Fig. 2, in (A) all the nodes are in normal status and there is no forest fire detected. The direction of blue arrow in the figure indicates the original parent node. In Fig. 2 (B) when node B detects a fire, it changes its status to UNSAFE and sends a TC message to all its neighbours in order to inform them about its status. At the same time, nodes G, E, F and D change their parent node to node B in order to fully used the node B's energy. As a result, this saves the energy of nodes A and C. While the fire enlarges, the other nodes will also be affected by the fire. In Fig. 2 (C), another node which is node F detects a fire and changes its status to UNSAFE. Node F then informs all its neighbours about its status, and consequently nodes H, L, I, K, J change their parent node to node F. In another scenario as shown in Fig. 2 (D), nodes B and F are regarded as FAILED since these nodes have detected more than 100 degree Celsius temperature. The highest temperature for the node to function correctly is 130 degree Celsius [18]. In this case, once the temperature reaches this value, nodes B and F will be destroyed by the fire. These FAILED nodes will be removed from the routing table to avoid broken routes. To achieve this, the route cost for FAILED nodes will be increased to infinity. Therefore, protocol will start a new route discovery process for routes involving these two nodes. In addition, neighbours nodes that are located one-hop away from nodes B and F will change their status to LESS SAFE.

IV. SIMULATION SCENARIO FOR THE FOREST FIRE DETECTION

We compare our proposed PCE-OLSR routing protocol with original OLSR protocol [17] and the simulation is done in MATLAB software. The simulation environment is assumed to be a square forest of 1000x1000 m^2. There are 50 nodes deployed in the environment for monitoring purpose. Each node has a circular coverage zone with a radius of 250m. Each can only move within a circle with diameter equals to 125m. Each node starts with initial energy equals 2 kJ. In normal condition, the temperature of the node is 20 degree Celsius. This reading will be increased when the nodes sense the area.

The experiment time is set at 1500 sec, and we have presumed that the forest fire has been initiated after a period of 400 sec. The starting location of the fire is chosen to be near the center of the network field. Fig. 3 shows the simulation scenario. The fire is assumed to spread in circle with increasing length radius and the speed of the fire is 0.5 m/sec. The maximum value of the fire radius is 300 m. Each node generates one packet at mean time 15 second. The data packet lifetime is set to 15 second. The other simulation parameters for the proposed PCE-OLSR routing protocol are presented in Table II.

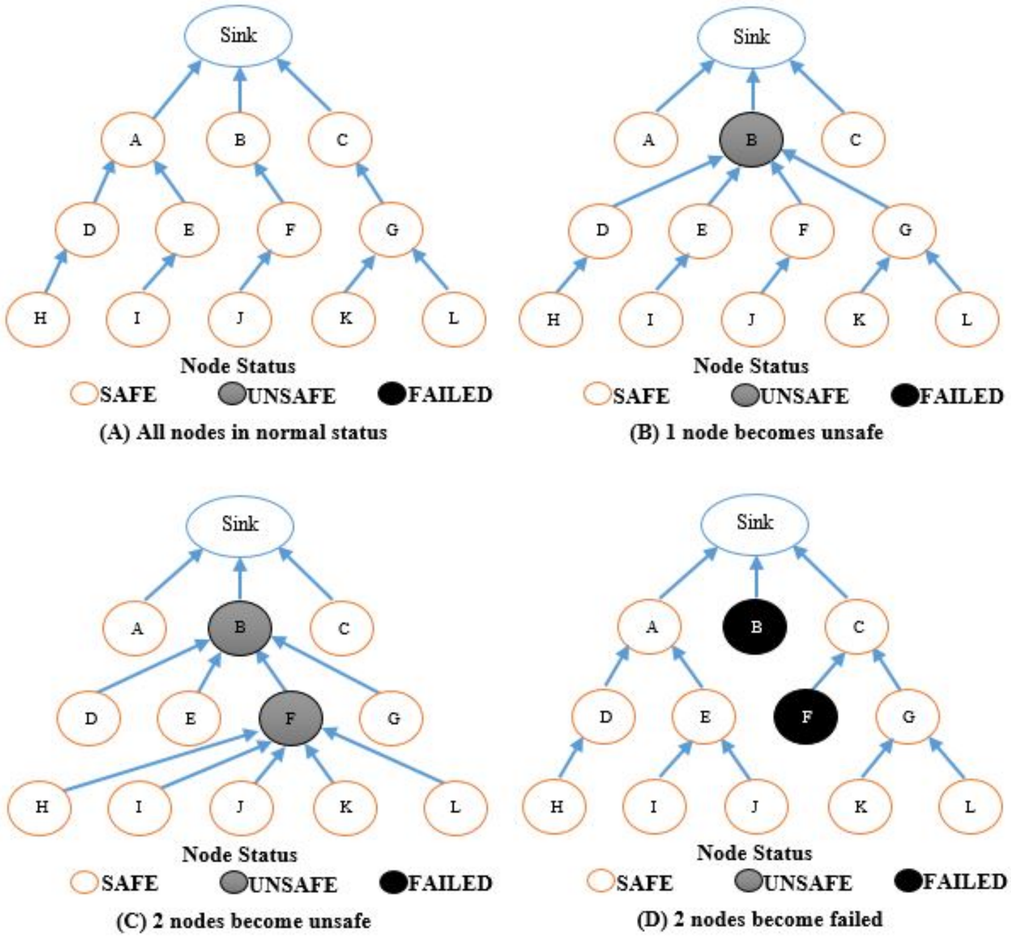

Fig. 2. PCE-OLSR Diagram

TABLE II. THE SIMULATION PARAMETERS FOR THE PCE-OLSR PROTOCOL

Parameters	Value
Experiment duration	1500 [sec]
Rate of logging data	25 [sec]
The moment of fire	400 [sec]
Number of nodes	49 node
Initial node energy	2 [kJ]
Coverage zone radius	250 [m]
Average size of packet	80 byte
Node initial temperature	20 [^{0}C]
Node velocity	Randomly distributed in [7.5 - 12.5] m/sec
Fire speed	0.5 m/sec
Fire radius	300 [m]
Environment dimensions	1000*1000[m^2]
Start point of fire	Randomly chosen to be near the center of network field
Data buffer size	100 packet
Data packet lifetime	15 [sec]
Interval arrival time	15 [sec]
Data packet generation mean	1 packet
Time unit	10 ms
Performance Metrics	Routing Overhead, Packet Delivery Ratio, Energy Consumption and End-to-End Delay.

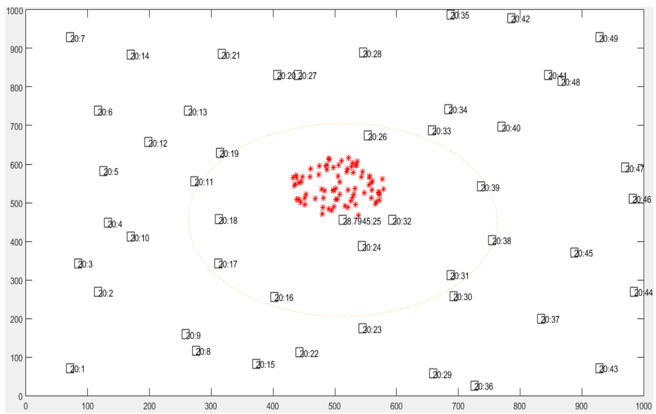

Fig. 3. The simulation scenario

V. PERFORMANCE MEASURES

In this simulation, four performance metrics are used to evaluate and analyze the proposed PCE-OLSR performance. The details are as follows:

A. Packet Delivery Ratio (PDR)

$$\text{PDR}\ (\%) = \frac{\sum \text{No of packet received}}{\sum \text{No of packet sent}} * 100 \qquad (1)$$

B. End To End Delay (E2E delay)

$$\text{E2E Delay (sec)} = \frac{\sum(\text{arrive time} - \text{send time})}{\sum \text{No of packets}} \qquad (2)$$

C. Routing Overhead (RO)

$$\mathrm{RO} = \frac{\text{Total number of control packets}}{\text{Number of recived packets}} \quad (3)$$

D. Average Energy Consumption (AEC)

$$\mathrm{AEC} = \frac{\sum \text{energy consumed in each node}}{\text{network initial energy}} \quad (4)$$

VI. Results and Discussion

Comparison and evaluation between the proposed PCE-OLSR protocol and the standard OLSR protocol are presented in order to precisely determine which of these routing protocols is more efficient and reliable to detect the fires in the forest. Fig. 4 shows the results of PDR for PCE-OLSR protocol and OLSR. The performance of routing protocols before and after the ignition of the fire is differentiate with the light blue line. The intention of this simulation is to evaluate the performance of the proposed PCE-OLSR protocol with OLSR protocol in the forest fires. After the fire occurrence, PCE-OLSR protocol achieves PDR value equal to 47.74%, while the OLSR protocol obtains PDR value equal to 29.38%. Thus, the PCE-OLSR protocol has better performance than OLSR in terms of the PDR, wherein it can be seen in Fig. 4 that the PCE-OLSR protocol obtains a higher amount of received data as compared to the OLSR.

Fig. 5 shows the comparison between PCE-OLSR and OLSR in terms of energy consumption. Each sensor node in the network is assumed to have an initial energy of 2000 J. Right before the ignition of the fire, PCE-OLSR protocol has mean energy consumption of 1450 J and OLSR has mean energy consumption equal to 412 J. After the occurrence of the fire, the PCE-OLSR and OLSR have different performance, where the mean energy consumption in PCE-OLSR protocol is 308 J and the mean energy consumption in OLSR protocol is 216 J. It is obvious that the energy consumed by the nodes when using the proposed PCE-OLSR protocol is less than the traditional OLSR protocol. This eventually shows that PCE-OLSR protocol has managed to exploit the energy of the nodes that are located at the fire area and thus preserves energy of other nodes. Consequently PCE-OLSR prolongs the network lifetime compared to OLSR.

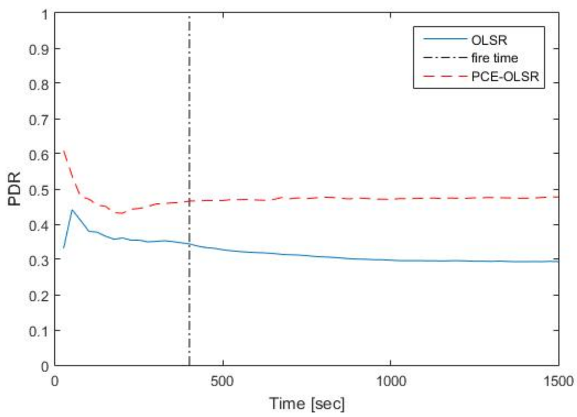

Fig. 4. PDR between PCE-OLSR and OLSR

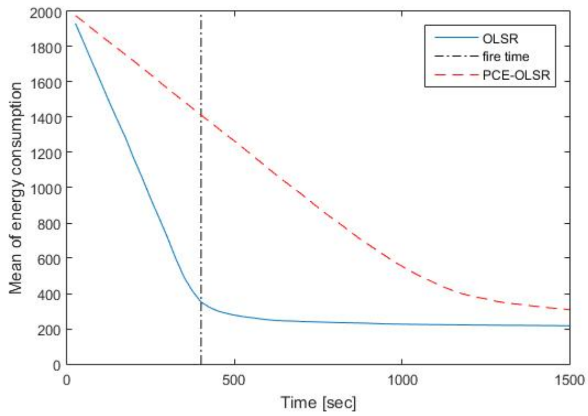

Fig. 5. Energy consumption between PCE-OLSR and OLSR

Fig. 6 shows the end to end delay (E2E) for PCE-OLSR and OLSR. The values of E2E delay for PCE-OLSR and OLSR right before the fire are 0.1353 sec and 0.9078 sec, respectively. After the fire, the PCE-OLSR has achieved average E2E Delay equal to 0.07014 sec while OLSR has longer delay which is 0.9644 sec. It is obvious that the proposed PCE-OLSR protocol outperformed OLSR in terms of E2E delay.

Meanwhile Fig. 7 shows the comparison of routing overhead between PCE-OLSR and OLSR. Nevertheless, the routing overhead of PCE-OLSR protocol is higher than the OLSR protocol. Therefore, OLSR has outperformed PCE-OLSR in terms of overhead. The reason behind this is because, the mechanism of PCE-OLSR protocol requires all neighbours of a node that detects and senses fire to change their parent node to this node that is located in the fire zone, in order to fully consumed this node's energy. Consequently, this process produces more control packets and hence, increases routing overhead in PCE-OLSR protocol.

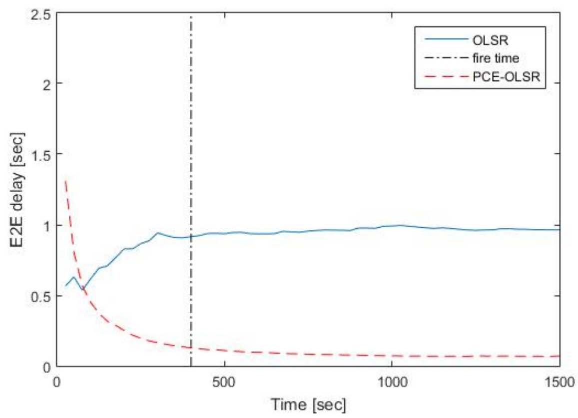

Fig. 6. E2E Delay between PCE-OLSR and OLSR

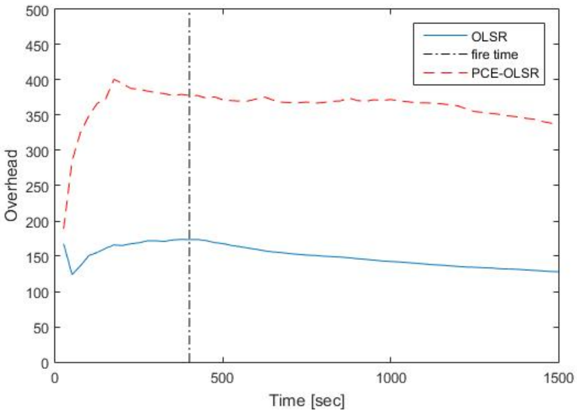

Fig. 7. Overhead between PCE-OLSR and OLSR

VII. CONCLUSIONS AND FUTURE WORK

Mobile sensor network has become an interesting field of research, due to the promising features, ease of deployment and reduction of cost which made this kind of network popular in many applications such as forest fire disaster. Therefore, this paper has presented a new routing protocol called Power Consumption Efficient-OLSR (PCE-OLSR) that it is based on OLSR protocol in order to detect fires in the forest efficiently. PCE-OLSR aims to save nodes energy and thus prolongs the network lifetime. To achieve this, PCE-OLSR elects nodes which are found in the fire zone in order to entirely use their energy before they are burnt and damaged in the fire. Subsequently, this conserves the energy of other nodes and thus increases the network lifetime. The performance of the proposed PCE-OLSR has been evaluated and compared with the traditional OLSR in terms of packet delivery ratio, energy consumption and end to end delay. Results have shown that PCE-OLSR outperformed OLSR in terms of packet delivery ratio, energy consumption and end to end delay. Thus, network lifetime of PCE-OLSR is higher than OLSR and at the same time this protocol can deliver the data to the destination effectively at lower delay. Nonetheless, the PCE-OLSR has higher routing overhead compared to OLSR due to the requirement to update nodes' routing tables during the fire detection. Future research includes the PCE-OLSR protocol performance evaluation in different simulation scenarios. For instance, it is possible to consider another network metrics such as packet size, network size and simulation time. Another future work is to consider more realistic scenarios in the forest such as the wind speed and sensing the smoke. This can make the routing algorithm more practical and efficient to be applied in the real world.

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