Energy-Efficient Fire Monitoring Protocol for Ubiquitous Sensor Networks

Heemin Kim, Ae-cheoun Eun, Sunyoung Han, and Young-guk Ha*

Department of Computer Science and Engineering, Konkuk University
1 Hwayang, Gwangjin, Seoul 143-701, Korea
{procan,syhan}@cclab.konkuk.ac.kr, darkfox1@naver.com,
ygha@konkuk.ac.kr

Abstract. Many countries are looking for ways to fight the forest fire at early stage using sensor network by integrating IT technologies. Studies are conducted in fire-related sensor network field in line with those changes, and the studies are broadly divided into efficient processing of fire data between sensor nodes and sensor network energy efficiency in case of fire. Thus, this study forms multi-layer cluster hierarchy dynamically according to the direction of fire spreading on cluster-based network hierarchy appropriate for Fire-Monitoring, and intends to propose Energy-efficient Fire Monitoring Protocol that can reduce energy consumption by the entire sensor network by performing efficient transmission of fire data.

Keywords: Fire-monitoring, forest fire detection, Fire-detection ,Energy-efficient routing, USN, Cluster-based sensor network.

1 Introduction

Sensor network is evaluated as one of the best systems that can be applied at current environment. However, sensor network has many problems in fire-Monitoring environment due to limited battery problems. Flat based routing-based Fire-Monitoring like SPIN consumes energy very quickly since all nodes detecting fire start communicating individually. The energy use is inefficient for layer routing like LEACH regarded as appropriate for Fire-Monitoring since cluster individually transmits fire data like flat-based routing.[1]

The use of energy is inefficient in these problems since the number of data transmission by nodes increases as the region gets wider and the number of nodes increases.[2][3][4]Therefore, this study proposes Energy-efficient Fire Monitoring Protocol(EFMP) that increases energy efficiency by reducing the number of transmissions of temperature data measured by sensors detecting fire from Fire-Monitoring environment to Sink Node by forming multi-layer cluster hierarchy dynamically according to the direction of fire spreading from cluster-base.

* Corresponding author.

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2 Design of Energy-Efficient Fire Monitoring Protocol

2.1 Structure of Energy-efficient Fire Monitoring Protocol

The features of EFMP are electing a Master Head that collects and manages information from Slave Nodes managing Cluster. The location of Master Head changes according to information on fire (direction of fire). The passage defines structural design of EFMP and algorithm and packet type for deciding a Master Head.
The changes in the election of a Master Head according to Fire Monitoring refers to the forming of optimal dynamic hierarchical cluster by electing an optimal Master Head according to the changes in case of fire. It results in energy efficiency by reducing the number of transmission paths at the time of transmitting information on fire unlike existing sensor routing. Fig. 1. is EFMP Protocol Stack which designed by this paper and broadly composed of sections responsible for hardware and sections forming protocol.

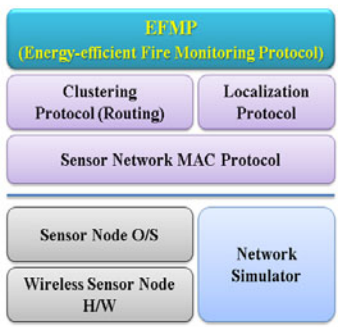

Fig. 1. Energy-efficient Fire Monitoring Protocol stack

2.2 Type of Packets

The features of EFMP are electing a Master Head that collects and manages information from Slave Nodes managing Cluster. The location of Master Head changes are according to the information on fire (direction of fire). The passage defines structural design of EFMP and algorithm and packet type for deciding a Master Head.

1) SIG_FIRE : Refers to a packet for detecting fire and sending detected information to Slave Node or Master Head and the conditions of sensor detection are decided by the following (1).

$$\left| \mathrm{TEMP(tn)} - \left(\sum_{t=t1}^{tn-1} \mathrm{TEMP}(t) / (n-1) \right) \right| > \Delta TEMPMAX \qquad (1)$$

Condition for detecting fire by SIG_FIRE Packet from EFMP

TEMP(tn) is currently measured temperature. $\sum_{t=t1}^{tn-1} t = \text{TEMP}(t)/(n-1)$ is the sum between TEMP(tn) and TEMP(tn - 1). It means average temperature prior to current temperature when $\sum_{t=t1}^{tn-1} t = \text{TEMP}(t)$ is divided by (n-1). From here, it means differences in average temperature of current temperature if $\left|\text{TEMP(tn)} - \left(\sum_{t=t1}^{tn-1} \text{TEMP}(t)/(n-1)\right)\right| > \Delta TEMPMAX$ and the differences can be regarded as temperature increase. Also, if the value $\Delta TEMPMAX$ is max, then it can be regarded as the highest temperature increase among increases in temperature. Therefore, it recognizes fire by detecting fire when it is higher than $\Delta TEMPMAX$ and sends information to Slave Node or Master Head. The composition of SIG_FIRE Packet is shown in Fig. 2.

TYPE	CONTENT	
SIG_FIFE	Sensor_ID	Sensor_data

Fig. 2. SIG_FIRE Message Format

2) SIG_DATA : Sensor monitors Fire and sends its information to Slave Node by recognizing fire. Sensor node receiving information relays data on fire (SIG_FIRE) it collected to a Master Head and SIG_DATA is used when sending information from Slave Node to the Master Head.

TYPE	CONTENT								
SIG_ DATA	Head_ ID	Num_ sensor	Sensor_ ID_1	Sensor_ data_1	Sensor_ ID_2	Sensor_ data_2	...	Sensor_ ID_N	Sensor_ data_N

Fig. 3. SIG_DATA Message Format

3) SIG_INFORM : SIG_INFORM packet is used when a new Master Head provides its own information to Slave Nodes. It is used when the first Slave Node detecting fire within Cluster is changed to the Master Head.

TYPE	CONTENT							
SIG_ INFORM	Head_ ID	Bat_ capacity	Num_ sensor	Sensor_ ID_1	Sensor_ data_1	...	Sensor_ ID_N	Sensor_ data_N

Fig. 4. SIG_INFORM Message Format

4) SIG_QUERY, SIG_RESP : Slave Node within Cluster transforms to the Master Head from Slave Node once the sensor detects fire within its own Cluster. Slave Node becomes a Master Head candidate and the previous Master Head questions whether it is appropriate as a Master Head to nearby Master Head candidates. The message format sending this information is called SIG_QUERY and response to this is called SIG_RESP.

TYPE	CONTENT					
SIG_ QUERY	Master_ ID	Num_ candidate	Candidate _ID_1	Candidate _ID_2	...	Candidate _ID_N

TYPE	CONTENT					
SIG_ RESP	Slave_ ID	Hops_to_ master	Num_ candidate	Hops_to_ candidate _1	...	Hops_t candid _N

Fig. 5. SIG_QUERY Message Format & SIG_RESP Message Format

5) SIG_LISTEN : Address information on new Master Head should be sent to nearby Slave Nodes once a new Master Head is elected. SIG_LISTEN Packet provides address information of newly elected Master Head.

TYPE	CONTENT
SIG_LISTEN	Master_addr

Fig. 6. SIG_LISTEN Message Format

6) SIG_TRANS & SIG_RESET : SIG_TRANS is used for registering information on new Master Head by receiving SIG_LISTEN packet from the new Master Head and is also used when Slave Node registers its own address information. SIG_RESET packet is used when the previous Master Head returns back to Slave Node by handing over its authority as a Master Head to the newly elected Master Head and when reverted previous Master Head is registering its information with the new Master Head.

2.3 Role of Cluster Head According to the Changes in Case of Fire Monitoring

Cluster Head decides Master Head according to the changes in case of Fire-Monitoring. Fig. 7 shows the changes in roles of nodes according to changes in case of fire and all nodes are initialized while in Watch Mode.

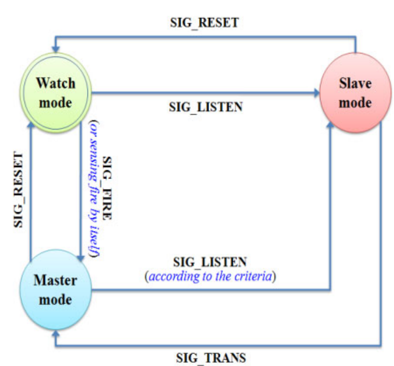

Fig. 7. Role of Cluster Head according to the changes in case of fire Monitoring

Watch Mode refers to initial state where sensors don't detect fire. Cluster Head that detects fire for the first time changes from Watch Mode to Master Mode. It transforms nearby Cluster Heads in Watch Mode into Slave Mode since it is in Master Mode itself under Master Mode. That is, EFMP System displays much better energy efficiency than existing cluster network since the system forms hierarchical networks dynamically by changing Cluster Head into Cluster Head Watch Mode, Slave Mode, or Master Mode according to the conditions of fire.

2.4 EFMP Detailed Operation Procedures According to Spreading of Fire

Cluster Head of EFMP operates in Watch Mode before detecting fire, monitors fire from own zone and collects sensor information. Sensor of Cluster Head in Watch Mode as shown in Fig. 8 sends fire information to own Cluster Head once fire is detected within own Cluster. Cluster Head receiving information of fire from sensor recognizes fire within own Cluster for the first time and sends information to Sink Node by converting to Master Head from Watch Mode.

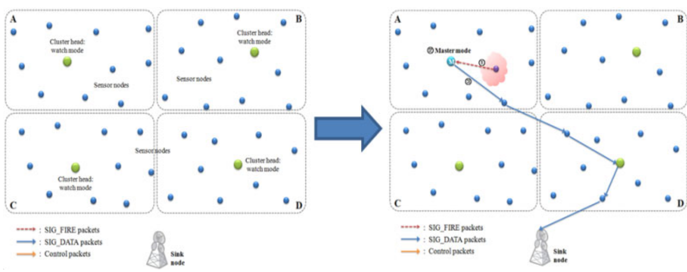

Fig. 8. Method of electing Master Head initially from Watch mode

First elected Master Head sends information on fire within own Cluster to Sink Node. It, then, sends Master Head information to nearby Cluster Head in Slave Mode through SIG_LISTEN message that is Master HEAD and updates. Cluster Head where fire broke out is elected as the first Master Head. A new Master Head according to the progress of fire sends collected data to Sink Node as shown in Fig. 9. It acts as the Master Head continuously until Master Head candidate appropriated for Master Head is elected again.

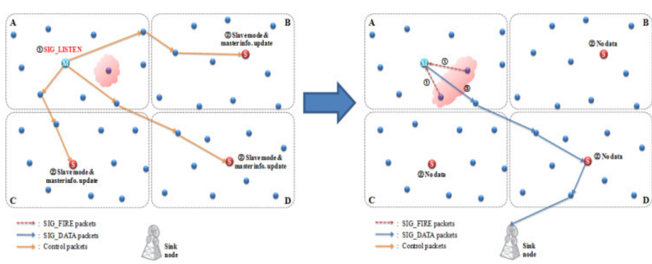

Fig. 9. Master Head Information Update through SIG_LISTEN Message

The header detecting fire for the first time is the most appropriate for a Master Head optimally since fire is not broken out from other areas for cases of Fig. 8, 9. However, reelection of optimized Master Head is necessary according to the range and information of fire if the range of fire extends to B, C Clusters as well as A Cluster as shown in Fig. 10. An optimal Master Head (Cluster Head detecting fire within own Cluster) elects a Master Head that has the least number of Hop counts between the number of Hops from Master Head candidate to Sink Node. The number of Hop on the sum of distance from other Cluster Head to Master Head candidate according to the range of fire. The least number of Hops refers to shorter distance for sending and using the least amount of energy. In other words, sensor information is collected by Cluster Head and collected information is not sent to individually to Sink Node by Cluster Head but by Master Head in batch. Master Head collecting information. Master Head can achieve efficiency in distance and energy used for sending information to Sink Node when selecting the least amount of Hop Count. thus the location of Master Head can be regarded as having direct effect on the efficiency of sensor network. The most optimized Master Head among Master Head candidates is the least number of Hop-Counts among candidate masters and the number of Cluster Heads increases detecting fire within own Cluster according to the spread of fire. Cluster Head detecting fire becomes a Master Head candidate that can become the Master and makes inquires to current Master Head on the conditions for becoming optimized master through SIG_INFORM message.

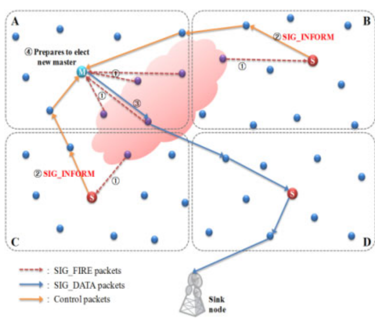

Fig. 10. Procedure of electing a new Master Head according to the range of fire

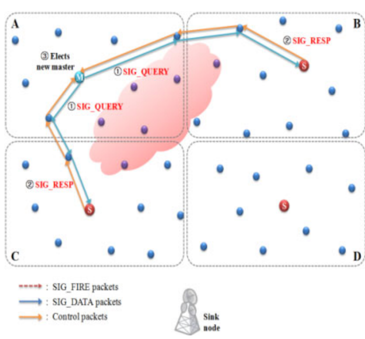

Fig. 11. Procedure of electing a new Master Head

The number of Cluster Heads detecting fire within own Cluster increases as fire spreads widely in Fig. 11. Cluster Head detecting fire can become a Master Head candidate can be master and inquires to current Master Head on the presence of conditions for becoming optimized master through SIG_INFORM message. Master Head receiving SIG_INFORM message sends SIG_QUERY message to send the total number of Hops to each Master Head candidate and Master Head candidates calculate the total number for Hops to Sink and send the information to the master through SIG_RESP message.

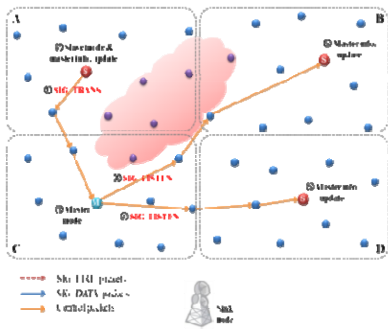

Fig. 12. Procedure of updating Slave Node by the changes in case of fire

When Master Head receiving the information, Master Head compares the total number of Hops on distance for sending messages to Sink and the number for Hops from each Master Head. Then, it informs a candidate with smaller number of Hops than itself if available as the next Master Head, while it sends message that it will maintain the role of a current master if the total number of Hops from Master Head candidates are bigger. Master Head moved to Cluster Head B from Cluster Head A since the fire spreads widely than in Fig. 13. Cluster Head B sends SIG_LISTEN, a packet requesting for updating new Master Head information to each Master Head candidates since it became the Master Head and Master Head candidates receiving messages update Master Head information.

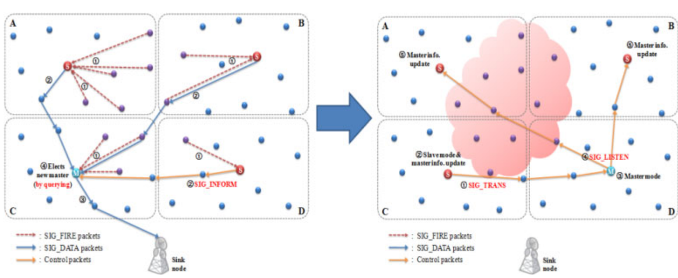

Fig. 13. Re-election of a third Master Head by the spread of fire

The previous Master Head updates information on the next Master Head by itself and does not update after receiving SIG_LISTEN since it knows which one is the next Master Head and sends SIG_TRANS message indicating completion of update thus elects a new Master Head. Elected Master Head relays information to Sink Node in batch by receiving information from each Cluster Head as the previous Master Head has been doing. The fire spreads wider than Fig. 13 to Cluster D. Cluster Head D realizes that it detected fire and notifies Master Head that it is now a Master Head candidate.

Master Head receiving information from Cluster Head D elects the next Master Head by comparing Hop-Count between own Hop-Count and Hop-Count of Master Head candidates. It is elected as a Master Head since Hop-Count from Cluster Head D is smaller than Cluster Head C. Each Cluster Head sends information collected from own sensors to Sink Node in previous Cluster Head method but there are problems of different energy efficiency in transmission by Cluster according to the location of Cluster Head, thus, the location of Cluster Head needs to be regularly changed to solve this problem. Otherwise, the entire energy efficiency on sensor network worsens according to several wrong locations of Cluster Head.

3 Performance Evaluation

OMNET++ 4.1 was used to test performance of EFMP in this study. MiXiM module was used to implement sensor network.

Fig. 14 is a graph showing average power consumption required for forming cluster without including data between node and cluster for 1 hour (3600 seconds). The y-axis of the graph shows average power consumption per sensor node as shown in the following formula. C(Si,t) is power consumed for time t by sensor Si and N is the total number of sensor nodes from (3).

$$\frac{\sum_{i=1}^{N} C(Si,t)}{N} \tag{2}$$

Formula for calculating average power consumption according to time

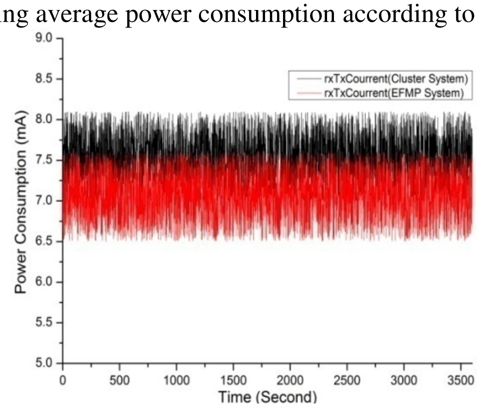

Fig. 14. Average power consumption per sensor by time

We know that existing clusters consume large amount of power to maintain connections from each cluster head to sink node when forming cluster head from Fire-Monitoring environment. However, other cluster heads send information only to Master Head and the Master head maintains connection to Sink Node once it is decided in EFMP under Fire-Monitoring environment. It is energy efficient since the number of transmissions from the entire sensor nodes are reduced by the Master Head. The results of testing show that EFMP is better in forming clusters and power for maintaining connections to Sink Nodes than existing clusters.

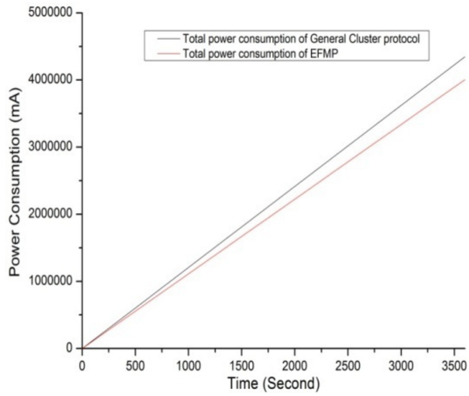

Fig. 15. Total accumulated power consumption according to time

Fig. 15 is a graph comparing accumulated power consumption according to the total time for sensor node participating under Fire-Monitoring environment. tc indicates current time and N indicates the total number of nodes participating in fire-Monitoring from (3). indicates the total power consumption by sensors according to time under Fire-Monitoring environment. The result shows the total accumulated power consumption by sensor nodes according to time as shown below.

$$\sum_{t=0}^{tc}\left(\sum_{i=1}^{N} \mathrm{C}(Si,t)\right) \tag{3}$$

Total accumulated power consumption by sensor nodes according to time

The results of test show that General Cluster Protocol used 4,346,675mA for 1 hour while EFMP used 3,933,713mA. EFMP reduced energy by about 9.5% according to the testing.

4 Conclusion

Sensor network is being evaluated as one of the most applicable system in fire-monitoring environment. However, sensor network has problems in fire-Monitoring environment due to limited battery capacity. The energy efficiency drops when general cluster sensor network is used when multiple sensors monitor fire over a wide area due to characteristics of Fire-Monitoring.[5][6]Therefore, this study proposed EFMP that reduces energy consumption from the entire sensor network by dynamically forming multi-layer cluster hierarchy according to the spread of fire and efficiently transmitting data in case of fire to cluster-based network hierarchy appropriate for the characteristics of Fire-Monitoring. The system reduced energy by about 9.5% than general cluster system through testing. EFMP showed better energy efficiency as the number of nodes increases in case of fire-Monitoring environment based on the regression analysis. The future study will be conducted to examine the size of fire by the spread of fire by expanding EFMP in fire-Monitoring environment. It is hoped that more studies on protocols will result in protecting lives and properties much quickly from fire.

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