Priority Based Routing for Forest Fire Monitoring in Wireless Sensor Network

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***Abstract*—Recently, forest fire monitoring system in wireless sensor networks has received much attention. The conventional scheme receives fire alert data quickly to inform fire forest event to the sink. However, since two or more nodes may detect a fire, high priority fire detection data frequently collide. In this paper, we propose a new forest fire monitoring system in order to reduce dropped rate of high priority fire detection data, by specifying a high priority received data only immediately after fire detection and just before the destruction by fire. Furthermore, the node only transmits high priority data to a node which has a low possibility of destruction by fire for low end-to-end delay of high priority fire detection data. The simulation results show that our proposed scheme can reduce dropped rate of high priority data and the end-to-end delay compared with the conventional scheme.**

I. INTRODUCTION

Recently, Wireless Sensor Network (WSN) is expected as an effective tool for many applications such as environmental monitoring and tracing[1]. In WSN, the sink node gathers data from many sensor nodes. Nodes are expected to drive with limited energy for a long period of time because these nodes are small and lightweight. Nowadays, it is expected to use WSN for the forest fire event detection by periodically sensing the temperature, humidity and light in the huge forest. In forest fire monitoring, we have to consider the fact that nodes might burn down when the fire breaks out. Although there exist many routing protocols $e.g.$ LEACH[2], PEGASIS[3], TEEN[4], PEQ[5], none of them considers the case when some nodes are burned down. As a consequence of the fire event, it causes unavailable path between sensor nodes and sink. In order to overcome this path failure, unrecoverable path to the sink cases increasing delay. It is necessary to utilize energies of nodes which will be destroyed by fire because we cannot use the energy of burned nodes. Hence, Maximise Unsafe Path routing protocol (MUP) [6] is proposed. MUP is a routing protocol that maximizes the energy utilization of nodes that are going to fail sooner, in order to save the energy of the other nodes. Although MUP selects nodes that must be in a dangerous area, many data are accumulated in a buffer of a specific node for focusing data on this node. Thus, superfluous data concentration causes dropped data so that this node will improve burnt in the fire before sending all data. Moreover, MUP loses the high priority data $e.g.$, when a fire event is first detected reference, because MUP dose not consider the priority of each fire alert data. Thus, it cases significant packets loss.

In this paper, we propose two methods to achieve a lower dropped data packets rate and end-to-end delay. The first one is to limit attaching the highest priority only to truly urgent event data, $e.g.$ when a node detects a fire. The second one is to change the routing methodology. In our scheme, nodes which have high priority data transmit them to more survival node, while nodes who have less priority data transmit them to less survival node. In addition, we send high priority data ahead of low priority data for low dropped ratio and delay. The simulation results show that our proposed scheme can improve dropped rate of high priority data and the end-to-end delay of high priority data, whereas keeping as many transmission and reception data as the conventional method.

The remainder of the paper is structured as follows: related work is described in Section II. The conventional MUP is presented in Section III. Section IV explains the network configuration and forest fire scenario used in the simulation. Simulation results and analysis are discussed in Section V. The paper ends with conclusions in Section VI.

II. RELATED WORK

There exist many fire forest-specific routing protocols. Environmental Monitoring Aware routing (EMA)[7] and Delay-bounded Robust Routing protocol (DRR)[8] are proposed as path predictable methods in a fire event.

In EMA, when nodes detect fire event, they send data to the sink and then the sink informs every node in the network of the fire event. Therefore, only safe nodes relay fire alert data to the sink. However, node state information might quickly become antiquated since the fire spreads very fast.

On the other hand, DRR sends fire alert data and only uses more survivable nodes by leveraging neighborhood nodes state. Thus, DRR achieves better dropped data ratio and delay. However, DRR dose not consider network lifetime. Therefore, MUP [6] is proposed. MUP extends network lifetime by making the most of UNSAFE state nodes, which have detected fire and will be burned sooner or later.

Fire spreads in response to the influence of wind and a strong wind causes speedy fire spreading. Since sensor nodes have to monitor in case of fire, how fast fire spreads by wind is important to be evaluated in the simulation. Kim researches fire spreading in wind[10]

III. CONVENTIONAL METHOD MUP

MUP selects nodes which are going to be burnt earlier as forwarding nodes, in order to save the energy of the other nodes. MUP defines node health status to each node.

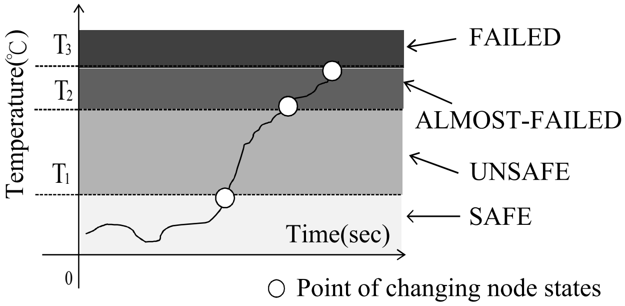


Fig. 1. Change state of detecting fire nodes.

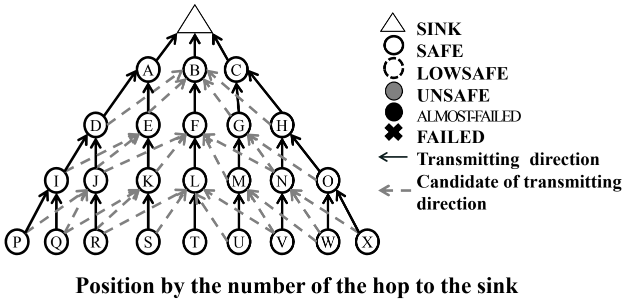


Fig. 2. Destination node selection without fire.

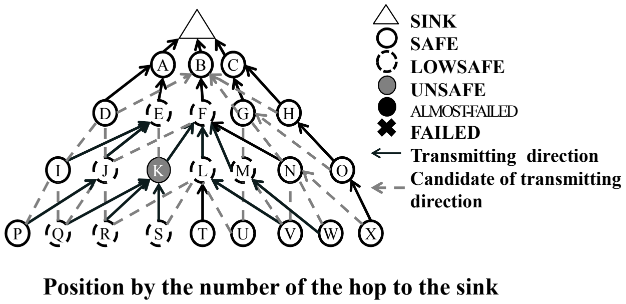


Fig. 3. Destination node selection with UNSAFE nodes.

MUP defines five levels of node health status:

· SAFE	Initial stage and while there is no fire.
· LOW SAFE	One-hop away from a detected fire.
· UNSAFE	Fire detected.
· ALMOST-FAILED	Just about to be destroyed.
· DEAD	Destroyed by fire or no battery.

In MUP, whenever a node detects that measured temperature is higher than a threshold, the node changes its state. Fig.1 shows an example of node health status against measured temperature. Nodes are always SAFE status in normal situation. A node detects fire when the temperature increases above a detection threshold that is set at $T_1 = 60^\circ$C. The node changes its health status to ALMOST-FAILED when this temperature reaches $T_2 = 100^\circ$C. The node is considered totally burnt in the fire when the temperature has reached $T_3 = 130^\circ$C , which is the maximum operating temperature for the node to function properly. Nodes change state LOW SAFE from SAFE when a neighbor located one-hop away from the node detected fire. All nodes send routing management messages including own health state periodically.

A. Data flow

In fire forest monitoring in WSN, nodes send their observed data to the sink by relaying some nodes. Normally, all nodes periodically send their observed data to the sink at long interval $e.g. 100sec$. But, when nodes detect fire, these nodes frequently send their observed data to the sink at short interval $e.g. 10sec$.

If a node detects a fire event, the node changes its parent node. MUP selects a parent node that must be in dangerous area in order to fully utilize its energy before being burnt in the fire. If one node has the lowest hop to the sink, then that node will be selected as the parent. However, if there are more than one node, the mechanism considers the nodes health status in the following order: UNSAFE, LOW SAFE and SAFE. The decision algorithm can be simplified as follows:

1) Nodes search the node with the lowest hop to the sink.
2) If there are more than one nodes, then selects the node according to these health statuses in the following order: UNSAFE,LOW SAFE, and SAFE.

ALMOST-FAILED nodes are excluded from forwarding node candidates for avoiding broken paths due to node failure. However, the mechanism selects these nodes as the parent node if there are almost-failed nodes only. Fig.3 shows an example of the way the MUP algorithm changes the routing three of the network when nodes have detected fires and then burnt in the fire. Fig.3 shows that MUP can utilize energy of node K which will be burnt in the fire.

B. Problem in MUP

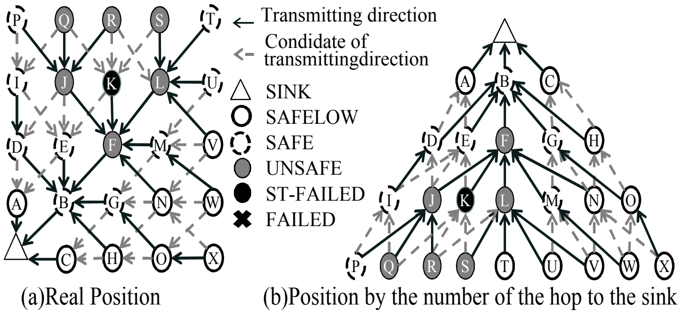
Although MUP selects a node that must be in a dangerous area, many data are accumulated in a buffer of a specific node by data centralization on this node. Thus, data overconcentration causes data dropped so that this node will be burnt in the fire before sending all data. At the same time, high priority alert data are dropped because MUP dose not consider the priority of each alert data. Fig.4 shows an example of dropped high priority data. In Fig.4, around node K nodes find fire diffusion after node K detects initial fire. Node J, L, Q, R and S select node K as their parent node and then send high priority fire detection data. These high priority data may be dropped in node K due to the superfluous data concentration with fire.

IV. PROPOSED METHOD

In this paper, we propose to send high priority data to more survivable nodes in order to reduce dropped rate of high priority fire detection data. We set high priority only after fire detection and just before destruction by fire. Furthermore, nodes send high priority data ahead of low priority data to achieve low dropped ratio and small delay. This can be executed by sorting the buffer.

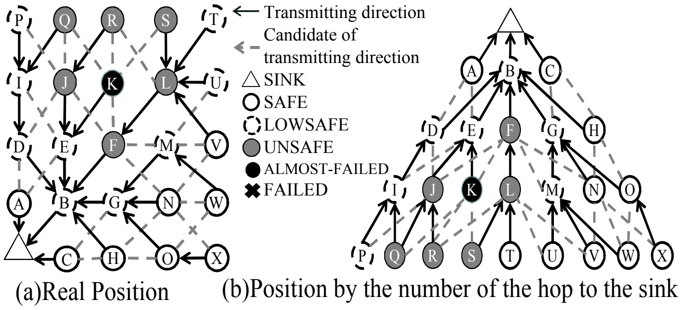
A. Priority fire detection data

Our method attempts to select a parent node depending on the priority of alert data. ALMOST FAILED nodes are



(a)Real Position (b)Position by the number of the hop to the sink

Fig. 4. Example of dropped high primary data.



(a)Real Position (b)Position by the number of the hop to the sink

Fig. 5. Data transmission of second priority data of fire detection.

removed as forwarding node candidates in order to avoid broken paths due to node failure. Therefore, we set three ranks of priority to alert data depending on three node status (UNSAFE, LOW SAFE and SAFE). Here, priority 3 is the most important alert date. We set the highest priority 3 to the alert data when each node detects fire since fire detection in an early stage is the most important. Then we set other fire detection data to priority 1 or 2. We set priority 2 with a probability P_1 for the fire detection data to be dropped. So, we set priority 1 with a probability $1 - P_1$ in order to avoid excessive increase of high priority data. And furthermore, we set priority 2 to the alert data of changing state to ALMOST-DEAD because the node may not generate any more data by the destruction. Also, we set priority 2 to the alert data of changing state to ALMOST-DEAD in order to avoid excessive increase of most high priority data.

B. Parent election

We send high priority data to a node far from fire, so as to avoid all priority data concentrated on a specific node. All nodes inform their health state of their health state in time unlike the temperature data. Note that each node recognizes neighborhood nodes state. TABLE I shows the parent election depending on the priority of alert data. Each node checks the neighbor node state with fewer numbers of hops to the sink than it self in order of TABLE I. When an applicable node is found, the node transmits data to the found node. If there is no candidate, the node looks up the routing table and finds the parent candidate who is as far as or further than it self. For example, when a node has three hops to the sink but this node only has neighbor node state with four hops, this node selects a node with four hops to the sink in order of TABLE I. When a node transmits the data of the priority 3, each node checks neighbor nodes state in turn from the SAFE state to ALMOST-DEAD state. And the node who has data of priority 2 checks in turn from the LOW SAFE state to ALMOST-DEAD state. Thence, the dropped ratio of the priority 2 data is declined and priority 2 data go through the different path from priority 3 data. Furthermore, each node has the fire detection data of the priority 1 checks in turn from the UNSAFE state to ALMOST-DEAD state. Thus we can utilize the energy before it is lost with the destruction by fire. Fig 5 shows data transmission of priority 2 data of fire detection. In Fig 5, priority 2 data concentrate node B whose state is LOW SAFE according to TABLE I. However, LOW SAFE nodes can send more data than UNSAFE state nodes because LOW SAFE state nodes have more time until being burnt by fire. Furthermore, LOW SAFE state nodes have high possibility of destruction by fire, so we can utilize the energy before it is lost with the destruction by fire.

TABLE I. THE PARENT ELECTION DEPENDING ON THE PRIORITY OF ALERT DATA

Order	Priority 1	Priority 2	Priority 3
1	UNSAFE	LOW SAFE	SAFE
2	LOW SAFE	SAFE	LOW SAFE
3	SAFE	UNSAFE	UNSAFE
4	ALMOST-DEAD	ALMOST-DEAD	ALMOST-DEAD

C. Sort in buffer

Data in the buffer are rearranged in the order of priority to send high priority data ahead of low priority data. Therefore, high priority data reach the sink early. Moreover, data dropped ratio decreases by transmitting high priority data before fire spreading.

V. PERFORMANCE EVALUATION

A. Simlation model

We evaluate the performance of the conventional and proposed schemes in terms of the dropped data ratio of fire alarm data, the delay of fire alarm data and the total number of transmitted and received data by detection fire node. Here, we evaluate the total number of transmitted and received data by fire detection node to show that the proposed method utilizes the energy before the destruction by fire as many as the conventional method. We define dropped data ratio as the ratio of the data which are not reached by the sink to all data generated by alive nodes. And we evaluate the performance of the MUP with priority and MUP with sort in

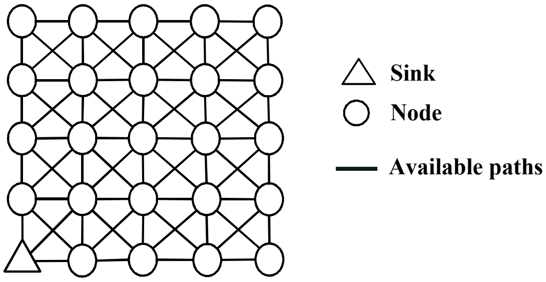


Fig. 6. Topology model

TABLE II. SIMULATION SPECIFICATIONS

Number of nodes	100 (10 × 10)
Distance between nodes	100 m
Node arrangement	Grid
Number of sink	1
Fire spread speed	5 m/sec
Time interval between fire alarm data	10 sec
Wind directions	5 directions
Wind speed	2 m/sec
Node states	5 levels
P_1	0.2,0.4,0.6,0.8,1
Bit rate	256 kbps
Data size	2560 B
Priority of fire alarm data	3 levels
Transmission Power	345 mW
Received Power	260 mW
Power consumption on idle state	13 mW
Power consumption on sleep state	0.19 mW
Simulation tool	C programming language

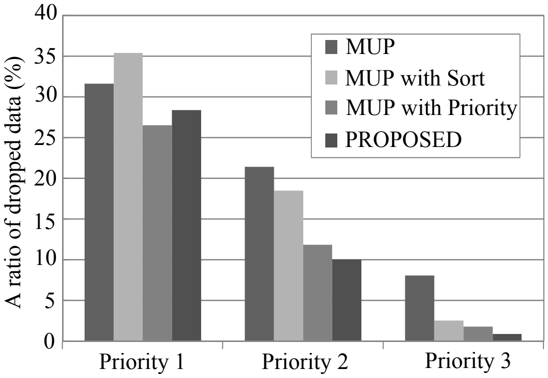


Fig. 7. Dropped data ratio of fire alarm data per data priorities.

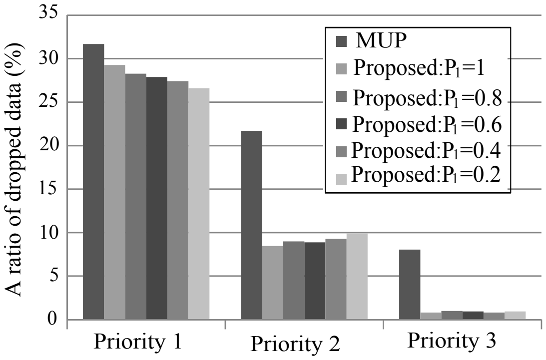


Fig. 8. Dropped data ratio of fire alarm data per data priorities changing P_1.

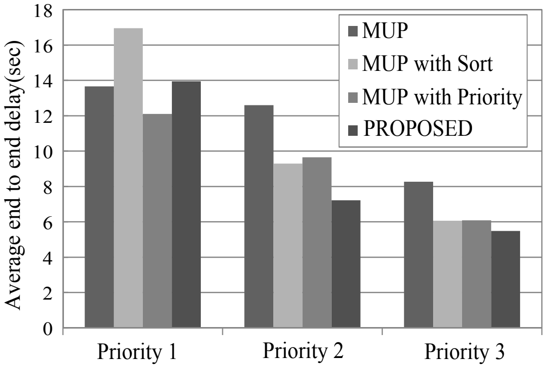


Fig. 9. Delay of fire alarm data per data priorities.

the same way to show the effectiveness by considering priority or sort data in MUP method. MUP with priority means the combination of node health status by MUP and parent selection method proposed by us, whereas MUP with sort means the combination of MUP parent selection and data sort method proposed by us. TABLE II shows the simulation parameters. These simulation parameters are based on [6][10]. Fig 6 shows topology model of this simulation. Then, initial fire randomly occurs from the node except the sink and then grows burning of about 40% of the network. Fire is diffused concentrically when the wind is not blowing. Although, fire spreads in direction of the wind when the wind is blowing. [10].

B. *Dropped data ratio of fire alarm data*

Fig.7 shows the dropped data ratio of fire alarm data per data priorities. From Fig.7, we can see that the proposed scheme and MUP with priority achieve better dropped data ratio of priority 3 than MUP. The proposed scheme reduces the dropped alert data ratio of priority 2 about 13% and priority 3 about 10% compared with MUP. This is because the proposed method transmits high priority data to more survivable nodes. And MUP with sort increases the dropped alert data ratio of priority 1. This is because alert data of priority 1 are transmitted after high priority data are transmitted by sorting the content of buffer at each intermediate node.

Fig.8 shows the dropped data ratio of fire alarm data versus probability P_1. From Fig.8, we can see that the proposed scheme achieves better dropped data ratio of priority 2 and 3 than MUP. This is because the proposed method sends high priority data ahead of low priority data. Furthermore, the ratio of dropped priority 2 data is increasing as P_1 increases for data centralization.

C. *Delay of fire alert data*

Fig.9 shows the delay of fire alarm data per data priorities. Here, we define the delay as the time from generating a data in a node to receiving this data by the sink. From Fig.9, we can see that the proposed scheme achieves better fire alert data delay of priority 2 about 38% and priority 3 about 29% than MUP. This is because data collisions of high priority are avoided by parent election of the proposed method. Moreover, proposed method and MUP with sort bring about delay of priority 1 compared with MUP because each node sends high priority data ahead of low priority data.

Fig .10 shows delay of fire alarm data per data priorities changing P_1. From Fig.10, we can see that the proposed scheme achieves better fire alert data delay of priority 2 as P_1 increases than MUP. This is because data collisions of high priority are avoided by electing a parent and sorting buffer of the proposed method.

D. *Total number of transmitted and received data by fire detection nodes*

Fig .11 shows total number of transmitted and received data by fire detection nodes. From Fig.11, we can see that the proposed scheme achieves more number of transmitted by fire

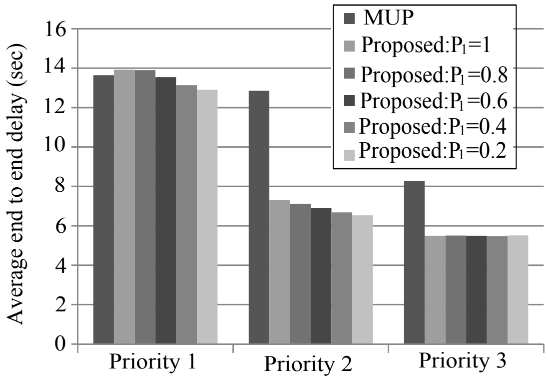


Fig. 10. Delay of fire alarm data per data priorities changing P_1

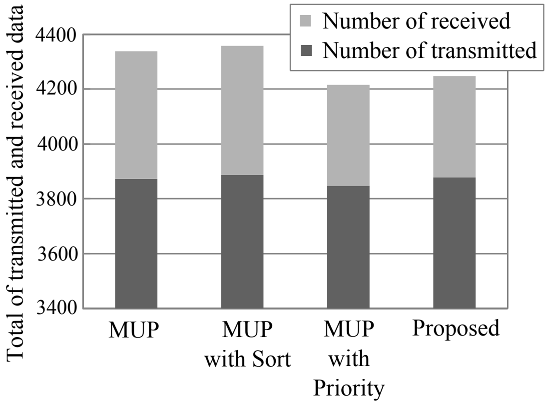


Fig. 11. Total number of transmitted and received data by fire detection nodes.

detection node than MUP. Total number of transmitted and received data of the proposed method is as many as MUP method , although the proposed method decreases the number of received data by fire detection node compared with MUP method.

Here, total number of transmitted and received data in MUP and MUP with sort are almost same. The reason is that parent selection method of these schemes are same. The proposed method controls the total number of transmitted and received data by the fire detection nodes approximately 2% of decrease compared with MUP method. Fig.12 shows total number of transmitted and received data by fire detection nodes changing P_1. From Fig.12, we can see that the proposed scheme keeps the total number of data transmitted and received by the fire detection nodes as many as MUP method.

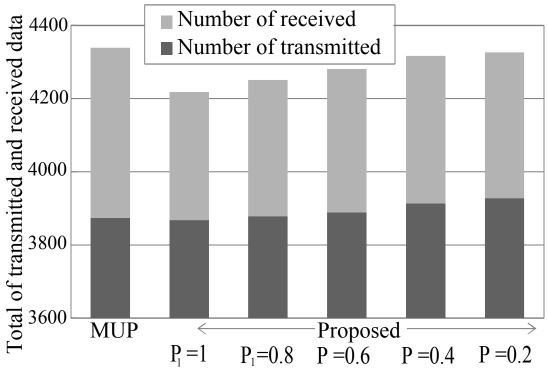


Fig. 12. Total number of transmitted and received data by fire detection nodes changing P_1.

VI. CONCLUSION

In this paper, we have proposed a new forest fire monitoring system in order to reduce dropped rate of high priority fire detection data, by specifying a high priority on data immediately after fire detection and just before destruction by fire. Furthermore, the node only transmits high priority data to a node which had low possibility of destruction by fire to achieve low end-to-end delay of high priority fire detection data. The simulation results showed that our proposed scheme can reduce ratio of dropped high priority data and the end-to-end delay compared with the conventional scheme.

ACKNOWLEDGMENT

This work is partly supported by the Grant in Aid for Scientific Research (No.23560465) from Ministry of Education, Sport, Science and Technology, Japan.

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