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Article

Energy-Efficient Forest Fire Prediction Model based on Two-Stage Adaptive Duty-Cycled Hybrid X-MAC Protocol

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Abstract: In this paper, we propose an adaptive duty-cycled hybrid X-MAC (ADX-MAC) protocol for energy-efficient forest fire prediction. The X-MAC protocol acquires the additional environmental status collected by each forest fire monitoring sensor for a certain period. And, based on these values, the length of sleep interval of duty-cycle is changed to efficiently calculate the risk of occurrence of forest fire according to the mountain environment. The performance of the proposed ADX-MAC protocol was verified through experiments the proposed ADX-MAC protocol improves throughput by 19% and was more energy-efficient by 24% compared to X-MAC protocol. As the probability of forest fires increases, the length of the duty cycle is shortened, confirming that the forest fires are detected at a faster cycle.

Keywords: Forest Fire; Prediction Model; Energy-Efficient; Sensors; WSN; X-MAC; Hybrid; Adaptive; Duty-Cycle; Protocol

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1. Introduction

Forest fire is characterized by rapid spreading according to the topography and slope of the mountain if they cannot evolve at an early stage due to their nature. Especially when the wildfires generated during the day are spreader, they cannot evolve and are transferred to deeper mountain area. And, an average of 340,000 people died every year due to forest fires in South Korea [1].

In South Korea, the average amount of simple damages caused by forest fires in the last 10 years is about 11.1 billion Korean Won [2]. Destroyed forests, damaged buildings and human costs are the ones that need to be avoided by the forest fires. In South Korea, the job as a forest fire watcher is operated separately by local governments, resulting annual human cost is estimated to be 650 million Korean Won per local government [1]. The goal of this paper is to replace or reduce such human cost. Figure 1 shows the following occurred number of forest fire in South Korea.

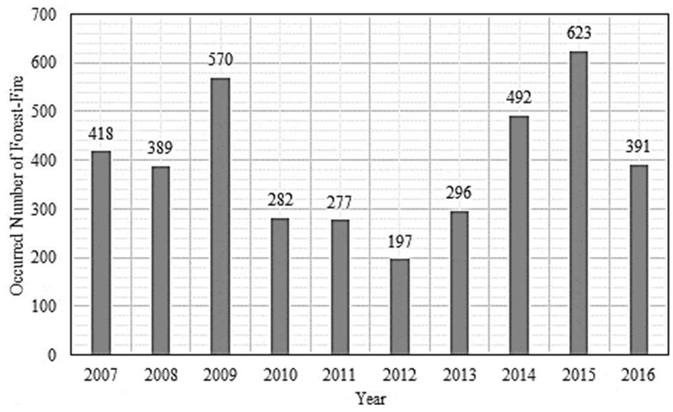


Figure 1. Occurred Number of Forest Fire in South Korea

It is necessary to think about the economic cost because it is to reduce human cost. When sensor is used, energy-efficient is the most considered part.

To save unnecessary energy consumption such as idle energy, someone propose a synchronous and asynchronous MAC protocol [3][4] that operates on the premise of a duty-cycle. As the number of connected devices increases, the traffic increases, but the duty-cycle of the nodes remains unchanged. As a result, the opportunity to send data decreases and the throughput decreases as the duration of the listening interval increases. In particular, because of the sudden bursting nature of forest fires, the amount of traffic detected by the initial sensors does not occur much, but as time passes, a lot of traffic occurs in a short time unit.

To solve this problem, we propose, ADX-MAC (Adaptive Duty-cycled hybrid X-MAC) protocol, is proposed based on X-MAC protocol [5] in order to implement the energy-efficient forest fire prediction system. that can reduce the energy consumption during sensor waiting time more efficiently and speed up the data transmission between nodes.

2. Forest Fire Prediction

According to the Forest fire prediction model [6], data on forest fires among the nationwide forest fire data for 25 years ranged from 1991 to 2015 were selected for the study. The data consist of 10,560 observations and information on areas, information, and characteristics of forest fires. Table 1 summarizes the variables included in the forest fire damage records [1][6][7].

Table 1. Fire damage data from the Model

Field	Description	Example
Year_No	Annual number (starting from 1 every year)	1
Month_No	Annual number (starting from 1 every year)	1
F_Year	Year of occurrence	1991
F_Month	Month of occurrence	1
F_Day	Day of occurrence	13
F_Time	Time of occurrence	13:40
F_Week	Date of occurrence	SUN
E_Year	Year of extinguish	1991
E_Month	Month of extinguish	1
E_Day	Day of extinguish	14
E_Time	Completion time of extinguish	14:55
R_Time	Extinguish time	19:30

Loc_Type	Station 1 (with errors)	Ulsan
G_Offices	Station 2 (with errors)	Ulsan
Loc_SiDo	City (Si), State (Do)	Ulsan
Loc_Gung	Street 1 (Gun, Gu)	Buk
Loc_Dong	Street 2 (Dong)	
Loc_Ri	Street 3 (Lee)	
PNU_Nam	Other addresses	Mt. 79-1
Owner_Ty	Ownership type	
F_Type	Types of forest fires	
F_Cause (11 things)	Cigarette burning, Trash incineration, Building fire transfer, Arson, Incineration of fields, Mistake from children, climbing, in operation and Others	Construction site, Bonfire
D_Area	Damage area	14
D_AreaU	Additional damage area	0
D_AreaT	Total damage area	14
D_Amount	Amount of damage	1260
Temprt	Temparutre	2.8
Wind_Dir	Wind direction	NNW
Wind_Sped	Wind speed	6
Humidity	Relative humidity	26
Lapse_Day	Elapsed days (days since rainfall (5 mm or more))	6
R_Amount	Rainfall	1.8
Coord_X	Coordinate of X (Location)	416976.8
Coord_Y	Coordinate of Y (Location)	229115.2
Reclass (6 things)	Cigarette burning, Trash incineration, Building fire transfer, Arson, Incineration of fields, Mistake from children, climbing, in operation and Others	
Address	City (Si), State (Do) (Including special metropolitan city)	Ulsan Metropolitan City, Bukgu
DO_Arr	City (Si), State (Do)	Ulsan
SI_Arr	Street (Gun, Gu)	Buk

2.1. Weight value from Prediction Model

According to the model, they used the weather and location information of the forest fire occurrence grid and the parameters for human accessibility. To use meteorological information, we used the space kriging technique. To generate the parameters for accessibility, we used the distance from the dense population to the grid where the forest fire occurred, the number of trails in the lattice, and altitude data. The data used in the study were changed to correspond to the 5 km grid. The logistic regression model was selected as the final forest fire prediction model and it was reflected in the monthly effect model using variable numbers for refinement. Because of the analysis, the predicted rate was 84.8%, which is very significant.

The main factors of forest fires are temperature, wind speed, humidity, and rainfall. Table 2 shows the results of the correlation analysis of climate factors according to the forest fire prediction model.

Table 2. Analysis of Correlation between Frequency and Climate Factors

Symbol (*X*)	Correlation	Test Statistics	Weight (w_X)
TP (Temperature)	-0.043	-0.7429	0.06
WS (Wind Speed)	0.304	5.5086	0.48
H (Humidity)	-0.198	-3.4870	0.3
R (Rainfall)	-0.105	-1.8226	0.16

The correlation coefficient between the number of forest fires and temperature (TP) is -0.043, and the test statistic for significance is -0.7429, which is almost not statistically significant. There is very small statistically meaningful association between temperature and the frequency of incomes. However, for the remaining wind speed (WS), humidity (H), and rainfall (R), the correlation coefficients are 0.304, -0.198, and -0.105, respectively, the climate factors other than temperature may have a meaningful connection with forest fires. In other words, when the wind speed is high, the humidity is low, and the rainfall is small, the possibility of forest fires is increased.

The correlation analysis of these main factors is converted into the approximated equation such as Equation (1), Weight Value of Occurred Forest Fire by Climate Factors. It also indicates the risk of forest fires.

$$f_{\text{risk}}(t) = \frac{\Delta_{WS}(t)}{\Delta_{TP}(t)\Delta_H(t)\Delta_R(t)} \quad (1)$$

Each Δ_X value is as shown in Equation (2). In this case, when a unit in time is called t and X is a factor, X_t is the measured value through the sensors, and X_{max} and $X_{\min}$ are the maximum and the minimum values during the unit period of the arbitrary mountain region.

$$\Delta_X(t) = \begin{cases} w_X \dfrac{X(t) - X_{\min}}{X_{\max} - X_{\min}}, & X(t) > X_{\min} \\ 1, & X(t) \le X_{\min} \end{cases} \quad (2)$$

w_X is the correlation coefficient of Table 1, which is a weight value for each climate factor. Therefore, each Δ_X is a weighted ratio to a uniform average change of all factors.

2.2. Risk Analysis of Forest Fire from Test Statics and Weight value

The following Tables 3 and 4 analyze the climate factors of Gangneung and Surak Mountain in South Korea from January to October in 2017 [2][7]. In this table, the unit of WS is 'm/s', the H relative humidity, the unit is '%', the unit of R is 'mm', and the unit of TP is '°C'. In addition, the Test Statics with Stair Function of the table is ranged from 0 to 5 levels, considering the minimum and maximum of each climate in the mountain range.

Table 3. Risk Analysis of Forest Fire in Mt. Gangneung

Symbol	Jan	Feb	Mar	Apr	*May*	Jun	Jul	Aug	Sep	Oct
Climate Factor Measured Value										
WS	3	3.1	2.4	2.8	***23***	1.9	2	1.6	2.3	1.9
H	43.3	38.2	48.5	44.3	***29***	61.4	67.9	74.4	61.2	67.2
R	48.5	3.5	48.4	39.8	***0***	27.2	238.1	444.1	45.7	114.5
TP	1.5	3.5	7.1	15.4	***17.9***	21.2	26.8	24.3	21.3	15.2
Test Statics with Stair Function (LEVEL)										
WS	0	0	0	0	***4***	0	0	0	0	0
H	2	3	2	2	***4***	0	0	0	0	0
R	4	4	4	4	***4***	4	2	0	4	3

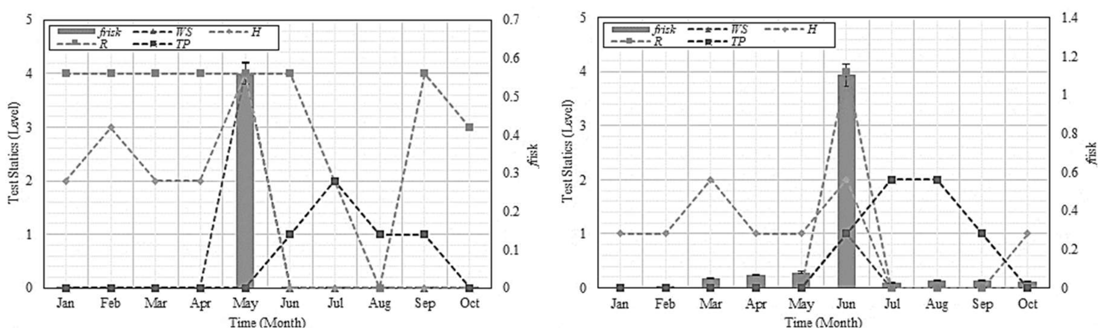
TP	0	0	0	0	***0***	1	2	1	1	0
Forest Fire Prediction Model (rounded value)										
f_{risk}	0	0	0	0.0001	***0.5610***	0	0.0003	0.0003	0.0001	0.0001

On 8 May 2017, when the forest fires occurred in Mt. Gangneung, the value of f_{risk} was 0.5610, which indicates that the risk of forest fires was very high.

Table 4. Risk Analysis of Forest Fire in Mt. Surak

Symbol	Jan	Feb	Mar	Apr	May	*Jun*	Jul	Aug	Sep	Oct
Climate Factor Measured Value										
WS	2.3	2.5	2.4	2.6	2.4	***5***	2	2.3	2	1.9
H	54.6	53.7	48.1	52.4	52.2	***43***	77.2	70.8	60.9	56.3
R	0	0	0	0	0	***0***	0	0	0	0
TP	-1.8	-0.2	6.3	13.9	19.5	***23.3***	26.9	25.9	22.1	16.4
Test Statics with Stair Function (LEVEL)										
WS	0	0	0	0	0	***1***	0	0	0	0
H	1	1	2	1	1	***2***	0	0	0	1
R	0	0	0	0	0	***4***	0	0	0	0
TP	0	0	0	0	0	***1***	2	2	1	0
Forest Fire Prediction Model (rounded value)										
f_{risk}	0.0006	0.0064	0.0469	0.0670	0.0806	***1.102***	0.0254	0.0385	0.0377	0.0332

Likewise, when the forest fires occurred at Mt. Surak on 1 June 2017, the f_{risk} was 1.102, which indicates that the risk of fires was immensely high compared to other days. They have shown that they can be trusted. and this f_{risk} is a core value of the protocol proposed in this paper and the next section. However, f_{risk} value does not necessarily show forest fire will occur, but the probability of occurrence is high. Table 2 and Table 3 are graphically shown in Figure 2.



(**a**) (**b**)

Figure 2. (**a**) Shows the change in the value of test statics with the duty-cycle length in Mt. Gangneung.; (**b**) Shows the change in the value of test statics with the duty-cycle length in Mt. Surak.

In Figure 2, The X-axis is time (monthly), the primary Y-axis is Test Statics, and the secondary Y-axis is value of f_{risk}. Each linear graph represents the level of the climate factor, and the bar graph is the value of f_{risk}. As can be seen in the figure, f_{risk} is most influenced by WS among the climate factors, but there are some factors considered by other climate factors.

3. Protocol for Energy-efficient Forest Fire Prediction

3.1. Duty-Cycled Wireless Sensor Networks

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X-MAC protocol [4] was proposed for solving the preamble overhearing problem of LPL (Low Power Listening) based B-MAC (Berkley-MAC) [8]. Of course, X-MAC uses all the basic methods of B-MAC, but unlike the long preamble of B-MAC, it transmits address of the node to the short preamble and as well as the listen period, so that they can tell if they will receive it.

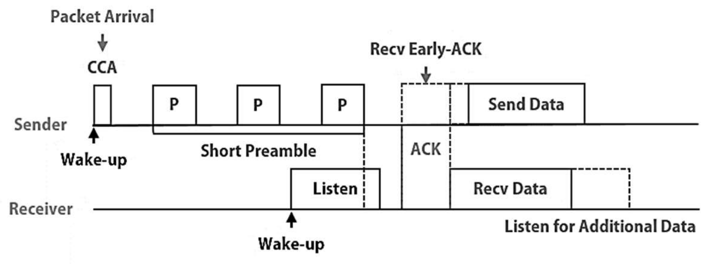

Figure 3. X-MAC Protocol

Figure 2 shows the difference between B-MAC and X-MAC. First, the node receiving the preamble containing its own address value sends an Early-ACK to inform itself of the reception of the preamble. The node that receives the Early-ACK stops transmitting the preamble and immediately transmits the data, thereby transferring data between the two nodes. When the receiving node receives the Early-ACK from the transmitting node without sending a long preamble, the transmitting node immediately sends data to reduce the unnecessary control packet overhead problem. Also, by checking the address value included in the preamble to the receiving node, the preamble that does not include its own address value enters the sleep state immediately, thereby effectively reducing the overhearing problem.

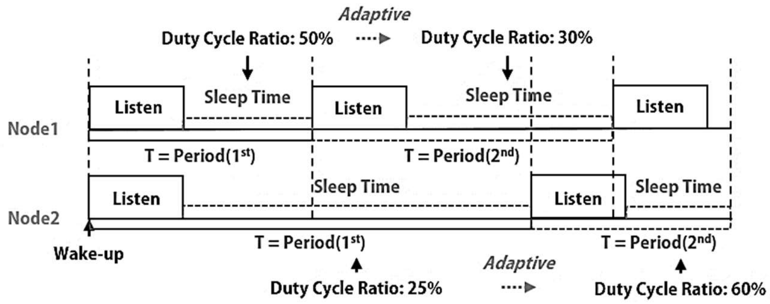

Figure 4. Adaptive Duty-Cycled Technique Works

Figure 3 shows how the Adaptive Duty-Cycled Technique (ADCT) [9] works. the X-MAC has a constant duty-cycle. However, when this technique is applied, the duty-cycle is changed according to the condition, and the size of the sleep interval varies depending on the situation.

Such a scheme has an additional effect, which has a similar effect to Contention Window (CW) [10] for preventing collision, so that the probability of collision at the same time (slot) is significantly reduced because Duty-Cycle of each node is staggered without Backoff [11]. This may reduce unnecessary delay by CW.

For example, when the number of packets in each nodes queue is smaller than the number of packets in the queue, the sleep cycle is increased by increasing the duty-cycle, thereby reducing unnecessary energy consumption. On the other hand, when the number of packets becomes larger, especially when the maximum size of the queue is reached, the duty-cycle is reduced as less as possible, so that the sleep interval can be shortened, and the traffic can be quickly resolved. By adapting the duty-cycle to the traffic situation, it improves the energy efficiency compared to the throughput by adjusting the unnecessary sleep interval and the time when the node wake-up.

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3.2. Adaptive Duty-Cycled Hybrid X-MAC

The proposed ADX-MAC applied such ADCT in X-MAC. The condition for controlling the duty-cycle length is the number of packets in queue and value of f_{risk}.

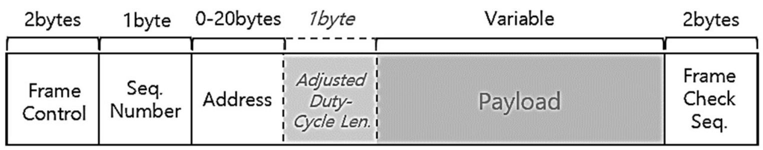

Figure 5. MAC Header (Data Unit) of ADX-MAC

Figure 4 shows the components of the MAC header (protocol data unit) in ADX-MAC. ADX-MAC is almost identical to the X-MAC. However, when the sender sends data to the receiver and the receiver and the sender have a similar cycle, the sender's own duty-cycle length value is included in the header content. This may also be included in the Early-ACK or ACK transmission phase, as opposed to the MAC Header of the Data Unit.

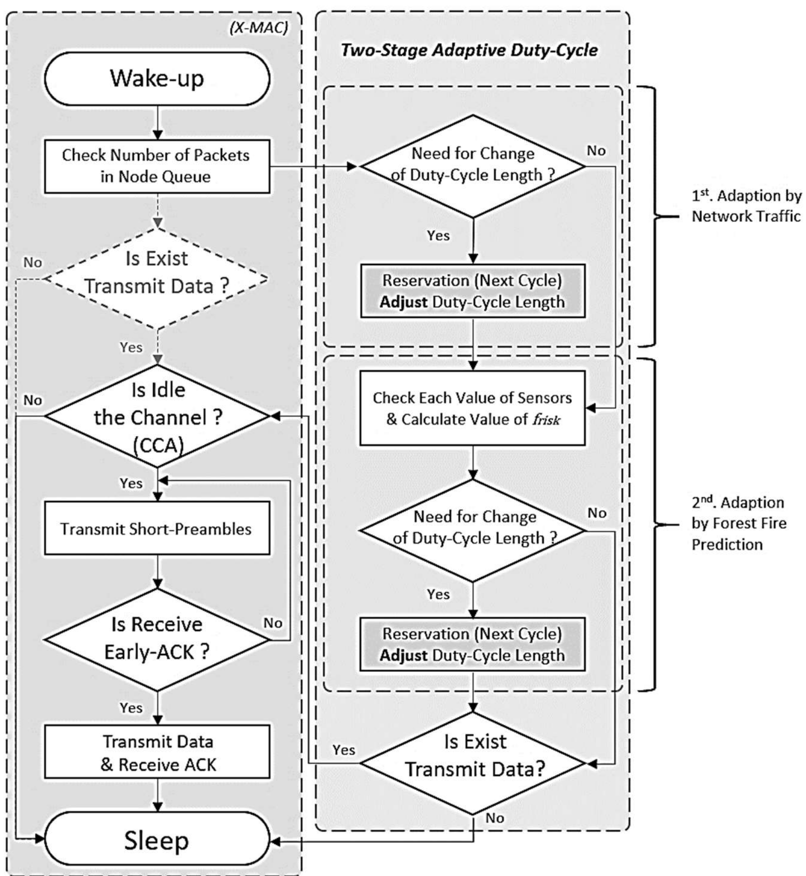

Figure 6. ADX-MAC (for Fire Forest) Algorithm

Figure 5 shows the algorithm of ADX-MAC. When the sender wake-up, the node queue status is first checked to see if there is data to be sent, and this operates like the X-MAC algorithm, but the X-MAC checks the channel status immediately, whereas the ADX-MAC checks the duty-cycle length determine if you need to change (adjust) the size. If the duty-cycle length needs to be changed, it is scheduled (reserved) to change in the next cycle. If no change is required, that is, if there is no difference from the previous cycle in the state of the queue, the process proceeds to the next step.

Equation (3) is the total ratio of the number of packets in the queue, which determines the duty-cycle length from the queue. In this case, $Q(t)$ is the number of packets queued at the current time unit t and $Q_{\max}$ is the maximum number of packets that can be queued.

$$Q_{\text{ratio}}(t) = Q(t)/Q_{\max} \tag{3}$$

The next step is to decide whether to change the duty-cycle length according to the f_{risk} value based on the measured value of the climate factor sensors. In order to make sure that there is data to send immediately. If it is necessary to change the duty-cycle length in the same manner as the previous step, it is scheduled to be changed in the next cycle. If no change is required, that is, if there is no difference from the previous cycle in the state of the queue, after checking the channel status, it transmits the short preamble until it receives Early-ACK. Then, after the data is transmitted, it is switched to the sleep state.

Equation (4) shows the f_{incr}, increase rate per unit time with f_{risk} in Equation (1) divided by the previous time unit t_0 and the current time unit t.

$$f_{\text{incr}}(t) = \begin{cases} f_{\text{risk}}(t)/f_{\text{risk}}(t_0), & f_{\text{risk}}(t_0) \neq 0 \\ 1, & f_{\text{risk}}(t_0) = 0 \\ 0, & t = 0 \end{cases} \tag{4}$$

The reason for dividing this into two-stages is that forest fires are likely to happen simultaneously, and congestion can occur due to the traffic congestion during one unit of time. Therefore, the number of packets in the queue is used to measure the congestion of the channel. And f_{risk} is to predict and respond quickly to the situation before it happens, or to send emergency data without interruption when a forest fire is occurring.

$$T_{\text{adp}}(t) = \begin{cases} 1 - (f_{\text{incr}}(t) + Q_{\text{ratio}}(t)) + f_{\text{incr}}(t)Q_{\text{ratio}}(t), & f_{\text{incr}}(t) \leq f_{\text{thd}} \\ 1 - (f_{\text{thd}} + Q_{\text{ratio}}(t)) + f_{\text{thd}}Q_{\text{ratio}}(t), & f_{\text{incr}}(t) > f_{\text{thd}} \end{cases} \tag{5}$$

Equation (5) is derived from the values of Equation (3) and Equation (4) and is the ratio of the initial duty-cycle length to the degree to be adapted. f_{thd} is an arbitrary value set to the limit value of f_{incr}. If f_{incr} becomes larger than f_{thd}, it is calculated as f_{thd} value instead of f_{incr} in the T_{adp} formula. This is because, if the change in climate factors is severe, T can become significantly large.

$$T(t) = \begin{cases} T_{\text{adp}}(t)T_0, & T_{\text{adp}}(t)T_0 \geq T_{\text{listen}} \\ T_{\text{listen}}, & T_{\text{adp}}(t)T_0 < T_{\text{listen}} \end{cases} \tag{6}$$

Equation (6) indicates that the duty-cycle length T value for the current unit time t is finally obtained through the values obtained from the equations (3) and (4). However, since T cannot be smaller than listen time (period), T_{listen}, if the calculated value is smaller than T_{listen}, T becomes T_{listen}. That is, in this case, the duty-cycle ratio becomes 100%.

4. Experimental Results

4.1. Verification of Adaptive Duty-Cycled Performance by Comparison with X-MAC.

The simulation environment is shown in Table 5. The simulation assumes the same environment, topography. Distances between all nodes are the same. In addition, packet generation is a CBR (Constant Bit Rate) method, and the network is always unsaturated.

Table 5. Simulation Environment for Network Topology

Parameter	Value	Parameter	Value
Bandwidth	250 *Kbps*	Node Queue Size	10
Sensing Range	250 *m*	Packet (Frame) Size	50 *bytes*
Data Transmit Rate	5 *ms*	Transmit Power	86.2 *mW*
Wake-up time	15 *ms*	Idle Power	52.2 *mW*
ACK transmit time	1 *ms*	Receive Power	96.6 *mW*
SP transmit time	3 *ms*	Sleep Power	0.0183 *mW*
Initial Duty-cycle length	100 *ms*		

The throughput, THR is obtained as shown in Equation (7) below. In this case, C_{ack} is the number of ACKs received by the sender until the end of the simulation, PKT_{size} is the packet size, and t_{stop} and t_{start} indicate the time when the simulation ended and the time when the simulation started, respectively.

$$THR = \frac{C_{\text{ack}} PKT_{\text{size}}}{t_{\text{stop}} - t_{\text{start}}} \tag{7}$$

The energy consumption E, is shown in Equation (8). In this case, PWR_{use} refers to the power used until the end of the simulation, and N refers to the total number of nodes

$$E = \frac{PWR_{\text{use}}}{N(t_{\text{stop}} - t_{\text{start}})} \tag{8}$$

In this experiment, f_{risk} of ADX-MAC is not considered. When comparing performance with X-MAC, there is no big difference even if f_{risk} factor works.

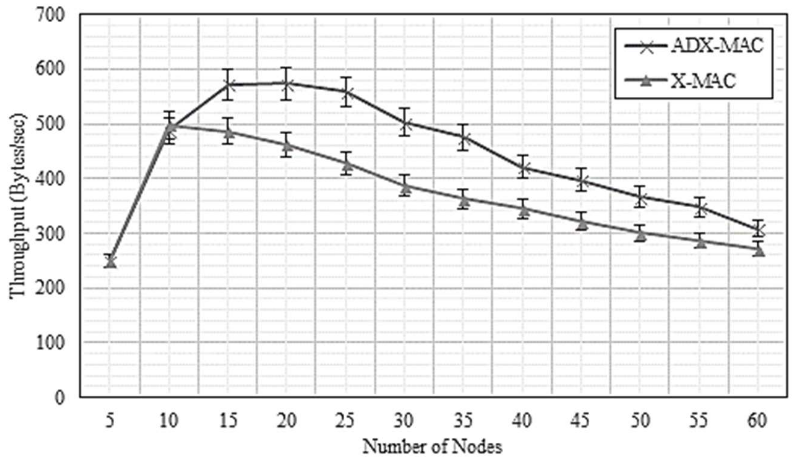

Figure 7. Throughput of ADX-MAC and X-MAC

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Figure 7 compares the throughput of ADX-MAC and X-MAC. In this case, the Y-axis is the value obtained from Equation (7) and refers to the throughput per unit time (second). The X-axis is the number of nodes. Although the efficiency between the two protocols is similar of until number of nodes is 10, but ADX-MAC has an average efficiency of about 24% higher than that of X-MAC since number of nodes is 15.

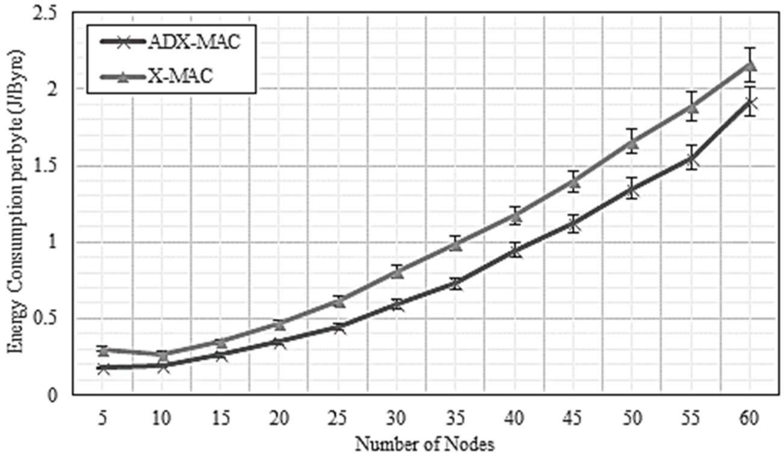

Figure 8. Energy-Consumption of ADX-MAC and X-MAC

Figure 8 shows a graph comparing energy consumption of ADX-MAC and X-MAC. the Y-axis is the value obtained in Equation (8), and the X-axis is the same as in Figure 7, is energy consumption per second per node. The average ADX-MAC efficiency was about 18% higher than that of X-MAC up to number of nodes is 25, but since that ADX-MAC was about 24% lower than that of X-MAC. As shown in Figure 6, this result is because ADX-MAC performs transmission activity about one-fourth times more than X-MAC as the number of nodes increases. Figure 8 shows the performance efficiency considering this.

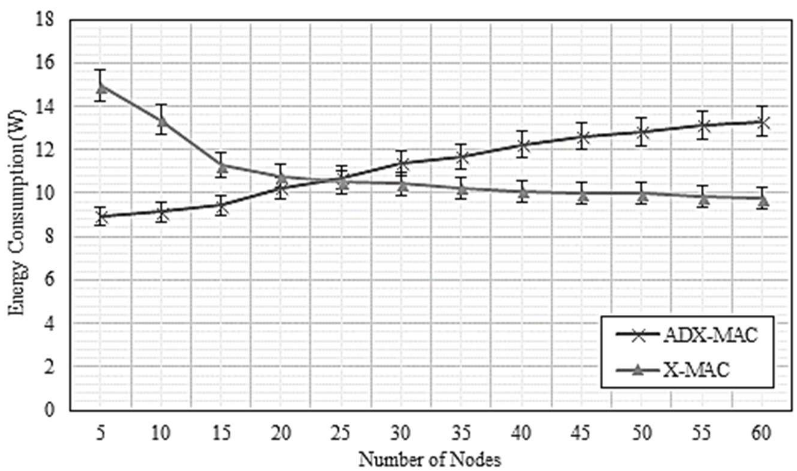

Figure 9. Energy per byte of ADX-MAC and X-MAC

Figure 9 compares ADX-MAC and X-MAC with consumed energy per byte, which is the average amount of energy consumed to transmit one byte until the simulation ends. The equation is shown in Equation (9) below, and the result is the X-axis of the graph, and the Y-axis is the same as the above graphs.

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$$E_{\text{byte}} = \frac{PWR_{\text{use}}}{C_{\text{ack}} PKT_{\text{size}}} \quad (9)$$

The amount of energy consumed per byte can be said to be always good because the ADX-MAC consumes less than the X-MAC over the number of intervals of all nodes. Although the efficiency of ADX-MAC is about 28% higher than that of X-MAC until the number of nodes is 35, the efficiency drops rapidly after that. However, the average number of nodes is about 17% in the range of 40 to 60. In conclusion, it shows about 24% efficiency in the all number of nodes.

4.2. Verification of Adapt Duty-Cycle Length from Climatic Factors

The purpose of this experiment is to determine how the duty cycle size T varies with the climate factor measured by the sensor. The network values used are the same as those used in 4.1. However, we do not consider the state of the queue in this experiment, as we did not consider f_{risk} in 4.1.

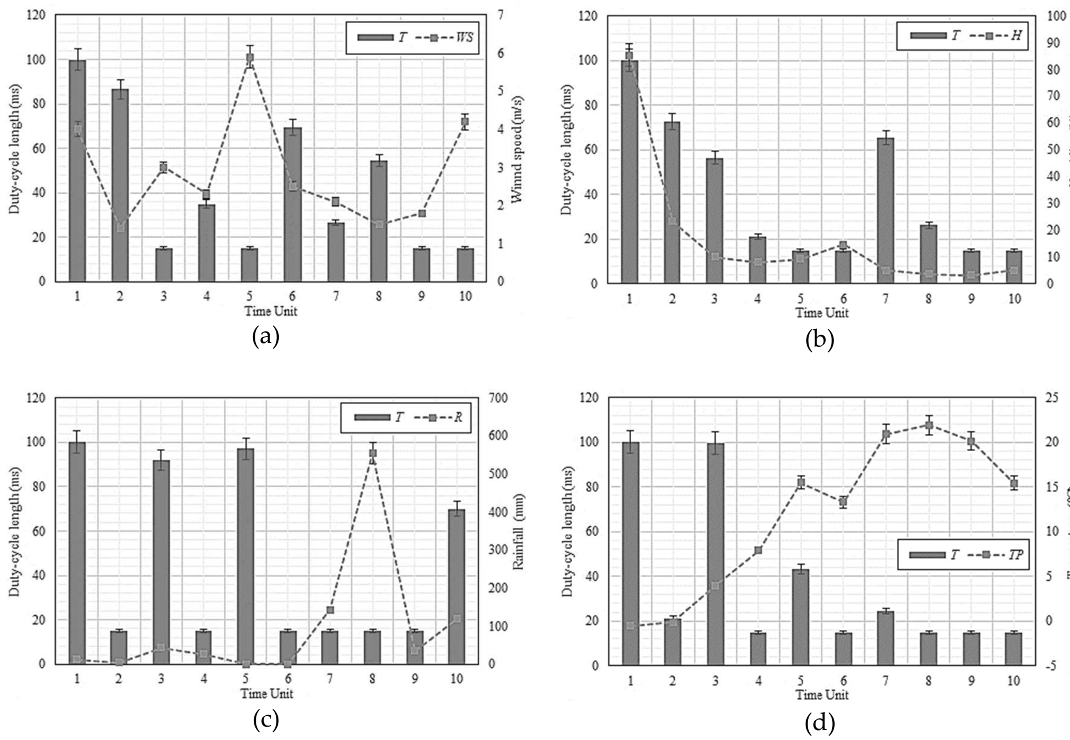

Figure 10. Each graph shows the change in duty-cycle length over time unit for each climatic factor. (a) Shows the change in the wind speed with the duty-cycle length.; (b) Shows the change in the humidity with the duty-cycle length.; (c) Shows the change in the wind speed with the duty-cycle length.; (d) Shows the change in the temperature with the duty-cycle length.

Figure 10 shows the change in duty-cycle length T for each climate factor. The X-axis represents the unit time, the primary Y-axis represents the duty-cycle length, and the secondary Y-axis represents each climate factor. In this case, the bar graph is the duty-cycle length, and the line graph is the value of each climate factor. At this time, the value of each climate factor does not consider the value of other factors other than those shown in the graph. In other words, we can see how the value of T changes when considering only the climate factors in each graph.

Figure 11 considers all climatic factors. The primary Y and X-axes are the same as in Figure 10, and the secondary Y-axis is the value of f_{risk}. The bar graph shows the value of T as in Fig. 10, and the line graph shows the value of f_{risk}. In addition, the trend line is represented by these two values.

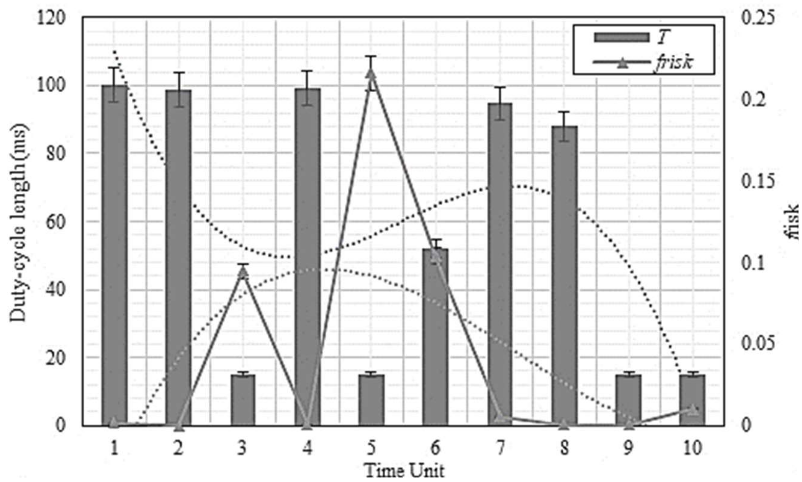

Figure 11. Change in the f_{risk} with the duty-cycle length per time unit

This allows us to see how the value of T changes as f_{risk} changes. That is, the high value of f_{risk} derived from the forest fire prediction model means that the probability of forest fires is high, so the duty-cycle length is shortened, and the forest fire sensing is performed at a shorter cycle per unit time.

5. Conclusion

The goal of this paper was to propose a forest fire prediction method on sensor to replace or reduce the existing human cost and to reduce the economic hit by forest fire and propose Wireless Sensor Network (WSN) MAC protocol for the problem. has verified a model for predicting the occurrence of forest fires and proposed ADX-MAC (Adaptive Duty-cycled hybrid X-MAC) protocol, which is a WSN MAC protocol based on X-MAC. The key factors of the proposed ADX-MAC were to adapt duty-cycle length through two stages of different factors. The reason for dividing this into two-stages is that forest fires are likely to happen simultaneously, and congestion can occur due to the traffic congestion during one unit of time. The first stage's factor is f_{risk}, which is a formulation of a forest fire prediction model, and the second stage's factor is the number of packets in the node queue. Through these two steps, the ADX-MAC is able to adjust the duty-cycle length in consideration of the traffic situation and the probability of forest fire.

To verify this, we have conducted a comparative experiment with X-MAC. Have confirmed that ADX-MAC has an average throughput increase of about 19% and energy-efficiency of about 24% on average compared with X-MAC. The change of duty-cycle length according to f_{risk} was also investigated through the derived formula and experiment. As the probability of forest fires increases, the length of the duty-cycle is shortened, confirming that the forest fires are detected at a faster cycle.

In conclusion, WSN MAC protocol for forest fire, ADX-MAC is suitable future work is to apply the proposed protocol to various natural disasters. In addition, even if the forest fire is limited, the ADX-MAC sensor can be introduced into the existing infrastructure, and the economic cost will be greatly reduced.

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