A dynamic MAC protocol for wireless sensor network based network traffic monitoring and feedback

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Abstract

WSN application in coal mine gas monitoring protects safety production. In order to save energy consumption, SMAC use periodic listen and sleep mechanism, against the problem of fixed duty cycle causes increased delay, this paper puts forward a new MAC protocol—DSMAC(Dynamic SMAC)which can feedback the channel's congestion level reasonably and adjust the duty cycle dynamically. The dominant idea of the new scheme is to record the packet amounts in the sending stage by sensor nodes, and according to the packet sending rate every sensor node can change its listening time adaptively when synchronization cycle finished to minimize delay and collisions, saving energy and channel resources. The result of simulation shows that compared with other MAC protocols, the DSMAC protocol can improve network throughput and reduce energy consumption in coal mine gas monitoring environment.

Keywords: WSN, periodic listen and sleep, duty cycle, DSMAC

1 Introduction

With the rapid development of radio systems, on-chip system, wireless communications and low-power embedded technology, wireless sensor networks have emerged, and its characteristics of low power, low cost, distributed version and self-organization brings a revolution in information awareness [1-3]. Therefore, the applications of wireless sensor network in forest resources monitoring system will greatly improve the accuracy of monitoring data. Real-time acquisition of environmental information by sensor nodes, and being processed by the embedded systems, then transmitting the information to the monitoring terminal outside the wells through self-organizing wireless networks in multi-hop relay way, that can effectively compensate for the shortcomings of wired devices, and has many advantages such as cheap, portable, high reliability, scalability, etc. [4].

Wireless sensor nodes are generally battery powered; when the energy is exhausted and cannot replace the power supply, one of the major technical challenges ,the wireless sensor network facing, is that nodes should meet the requirements of low power consumption, making access to the entire network to work as long as possible [5].Media Access Control (MAC) protocol determines the use of radio channel to allocate the limited resources of wireless communication between the sensor nodes, then how to design energy-efficient, low-overhead, high but also scalability fair MAC protocol has become an urgent research topic in the field of wireless sensor networks currently.

Currently, wireless sensor networks with different characteristics and specific applications of MAC protocols have been proposed [6-10]. BMAC [6] uses the extended protocol preamble and low power listening technique to achieve low power communications, channel ruling by the clear channel assessment techniques, and the BMAC does not need to share scheduling information. Therefore, it has a higher throughput and lower latency However, not much advantage gained in reducing the energy consumption. X-MAC [7] protocols shorten the length of the leader sequence, while introducing a handshake mechanism to further reduce the energy consumption of transmitting the preamble sequence. The experiments show that X-MAC exhibit excellent energy efficiency, throughput, and delay in different network conditions, but its computational methods are very complex.

In order to meet the need of low-power sensor networks, Wei Ye et al proposed SMAC [11] protocol having a sleep mechanism. Based on the analysis of the working process of SMAC protocol, against the problem of fixed sleeping time, this paper puts forward a new MAC protocol—DSMAC (Dynamic SMAC) which can feedback the channel's congestion level reasonably and adjust the sleeping time dynamically.

The improved protocol has increased the throughput in coal monitoring environment, reduced the rate of package loss and energy consumption, showing good network performance.

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2 Analysis of SMAC protocol

Based on IEEE802.11 [12] protocol, SMAC is a competition-based distribution MAC protocol to meet the need of low-power sensor networks. It can make the sensor find the neighbouring nodes .without the scheduling of the master node, and reasonably arrange the time occupied by channel, having good scalability.

In order to reduce the energy consumption by nodes, SMAC using periodic listener / sleep mode of operation, turn off the wireless device node and set the timer to wake up and listen to other nodes during sleep. The advantage is the fixed sleeping time of each node, so it can't be well adapted to the changes of network traffic, resulting in unnecessary energy consumption. The time of a periodic listener / sleep is one frame, during which presents different working conditions, and the listening period is divided into three parts shown in Figure 1.

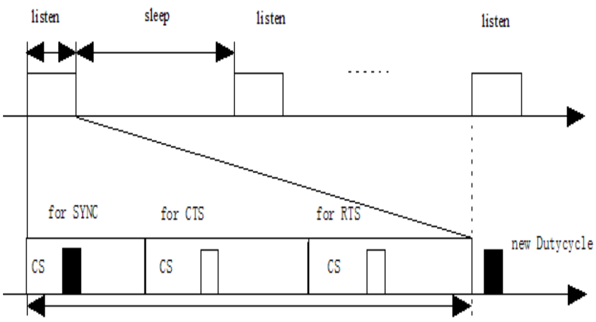

FIGURE 1 SMAC periodic listener / sleep and SYNC cycle

Compared with IEEE 802.11 protocol, SMAC greatly reduces the energy of nodes, thereby increasing the life of wireless sensor networks. The amount of saving energy consumption can be measured by duty circle, defined as follows:

$$Duty = \frac{T_{listen}}{T_{frame}} . \tag{1}$$

Thereby the saving energy ratio in SMAC protocol is:

$$E_{smc} = \frac{T_{sleep}}{T_{frame}} = 1 - \frac{T_{listen}}{T_{frame}} = 1 - Dutycycle , \tag{2}$$

$$T_{listen} = T_{SYNC} + T_{RTS} + T_{CTS} , \tag{3}$$

$$T_{frame} = T_{listen} + T_{sleep} . \tag{4}$$

It can be seen that the duty cycle marks the size of the node energy consumption. The larger the duty cycle is, the longer the node works, the greater the energy consumption is; the smaller the duty cycle is, the longer the node sleeps, though effectively reducing the energy consumption caused by the listener, the delaying time caused by the sleep will be longer. Below is the analysis on the issue.

For SMAC protocol the transmission of data packets from the source node to the next node will be affected by the delay, the paper analyses the delay of the packet when the network load is extremely light. Assuming that only one packet is transmitted in the network, it will not produce back off window delay and queuing delay. Moreover, the propagation delay and processing delay is very small, so it can be negligible. Therefore, the packet delays $D(k)$ in the k $(k=1,2,\ldots N)$ hop only need to consider sleep latency ($T_{s,k}$), competition delay ($T_{c,k}$) and transmission delay (T_{tr}).

The time simultaneous packet transmitted T_{SYNC}, so the packet delay $D(k)$ in the k $(k=1,2,\ldots N)$ hop is:

$$D(k) = T_{s,k} + T_{SYNC} + T_{c,k} + T_{tr} . \tag{5}$$

Then can be obtained:

$$D(k) = T_{frame} - T_{c,k-1} + T_{c,k} . \tag{6}$$

The total delay after N-hops:

$$D(N) = \sum_{k=1}^{N} D(k) = D(1) + \sum_{k=2}^{N} D(k) = D(1) + \sum_{k=2}^{N} (T_{frame} - T_{c,k-1} + T_{c,k}) . \tag{7}$$

After finishing it:

$$D(N) = T_{s,1} + T_{c,N} + T_{tr} + (N-1)T_{frame} . \tag{8}$$

Since the source node generates a packet at random, $T_{s,1}$ is evenly distributed within $(0, T_f)$, thereby the average delay of SMAC:

$$E[D(N)]_s = NT_{frame} - \frac{1}{2}T_{frame} + T_{tr} + T_c . \tag{9}$$

Without introducing sleeping mechanism, the average delay of IEEE802.11:

$$E[D(N)] = T_{SYNC} + T_c + T_{tr} . \tag{10}$$

T_{SYNC} can be negligible with a short frame. In SMAC protocol T_{listen} is fixed, so in order to reduce more energy consumption, we should use longer T_{frame} to reduce *Dutysysle*. However, the delay was linearly increased, which is the contradiction between the delay and energy consumption.

Meanwhile SMAC protocol uses a fixed duty cycle, when the networks load changes, adaptive capacity is relatively poor, and the delay is a serious problem. Therefore, how to dynamically adjust the duty cycle is an important direction sensor network MAC protocol design. So that it can adapt to changes in network load, which can reduce latency and increase throughput as well as maintain efficient energy utilization.

3 Relevant improvements about the MAC protocol

3.1 T-MAC PROTOCOL

T-MAC [13] (Timeout-MAC) protocol is proposed which is based on SMAC protocol. T-MAC protocol based on the unchanged cycle length, according to traffic to adjust activity time dynamically, T-MAC protocol reduces the idle listening time by means of sending a message with the burst mode. T-MAC uses the same frame size with SMAC and nodes are periodically awaked to listen. If there is no activation events that occur in a given TA (Time Active, each cycle determines the minimum idle listening time), the activity will end.

Based on traffic to adopt the dynamically changeable duty cycle, T-MAC protocol saves energy consumption, extending the life span of the network compared to SMAC protocol. However, because the node, which is beyond the scope of monitoring and needs to participate in data forwarding, cannot get timely information to extend the activation period and may be transferred to sleep early, resulting in "early to bed" problem. Thus, this reduces network throughput and increases network latency. In order to resolve the "early to bed" issue, T-MAC protocol raised two programs .One is request-to-send in future and the other is full-buffer priority, but neither is ideal.

3.2 AC-MAC PROTOCOL

AC-MAC is a flow-based adaptive SMAC protocol. It is the number of packets on the node of MAC layer that is the criterion to evaluate the node load. Moreover, based on the node load, it is to adjust the amount of SMAC within a communication cycle in order to adjust the duty cycle. It is shown in Figure 2.

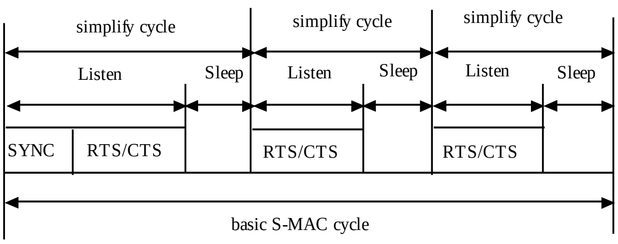

FIGURE 2 The AC-MAC new sleep cycle

The basic cycle is classified as several new simplified cycles on the basis of node queue load. Large loaded nodes can be awaked many times to get more opportunities to communicate without having to wait until the next time slot. Nevertheless, added to new simplified cycles, nodes can be frequently status switching and consumptive energy cannot be ignored.

Assume that node hibernation for energy is E_{sleep}, activity for energy is E_{listen}, the conversion time for the listen to the sleep is T_{ls}, the conversion time for the sleep to the listen is T_{sl}, then consumption of using a periodic listener /sleep strategy consumption $E_{lissten/sleep}$ is:

$$E_{listen/sleep} = \frac{1}{2}(E_{listen} + E_{sleep})(T_{ls} + T_{sl}) + E_{sleep}(T_3 - T_{ls}). \qquad (11)$$

The state of transition and energy is shown in Figure 3

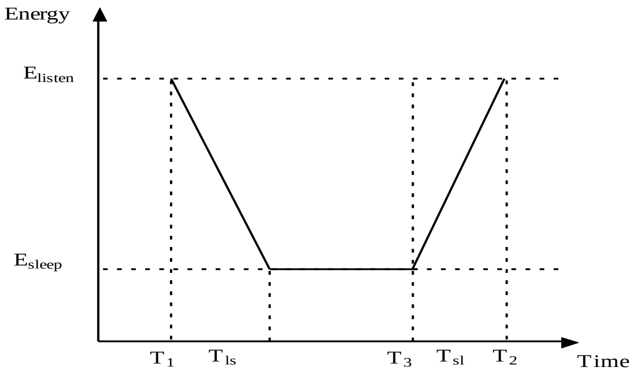

FIGURE 3 The state of transition and energy

3.3 MAC-ADCC PROTOCOL

ADCC (Adaptive Duty-cycle Based Congestion Control) By means of the dual monitoring the residual energy and network load conditions and feedback, it can adjust the duty cycle adaptively and reduce the collision and data retransmission. The results show that, ADCC-based MAC protocol reduces the average network latency in high-speed network environment and improves network throughput.

Meanwhile the literature, it is respectively proposed LQ-Tracking algorithm and TA-MAC to adjust the duty cycle dynamically to reduce collisions and to lower latency [16, 17]. However, because the introduction of more parameters and adjustment mechanism are quite much, so that the complexity of the algorithm increases certain energy consumption, and still needs further improvement.

3.4 DSMAC PROTOCOL

Based on the analysis of the above algorithm of duty cycle of several MAC protocols, we propose DSMAC. It is a SMAC-based protocol. Moreover, based on the rate of node synchronization cycle to send data packets, it can forecast network load in the future periods and adjust duty cycle dynamically. DSMAC solve in the dynamic changes in network load, SMAC protocol leads to the listening time adjustment ineffectively because of the fixed duty cycle mechanisms, resulting in the problem of excessive delays. However, DSMAC resolves this problem. And according to theoretical analysis, DSMAC does not cause excess energy consumption, and the algorithm is easy to implement and has a good network performance.

Here concepts of synchronization cycle and the data packet transmission rate and adjustment rules of duty cycle are defined and analysed.

Definitions 1. Adjacent nodes to regularly update listeners / sleep scheduling information cycle by sending SYNC frame is synchronized. With expression of Synchronization the default value is 10.

Synchronization cycle length is T_{SCYCLE}, the unit is *s*, the specific calculation method is as follows:

$$T_{SCYCLE} = SYNCPERIOD \times (T_{listen} + T_{sleep}) = \\ = SYNCPERIOD \times T_{frame} . \qquad (12)$$

Definition 2. The number of transmission packets per unit time is the packet transmission rate, by means of ∂. It is defined as:

$$\partial = \frac{totalpackets \times 50 \times 8}{T_{SCYCLE} \times 1000} . \qquad (13)$$

The unit is *kbit/s*. the number of transmission packets in the synchronizing cycle is showed by *totalpackets*, the size of a data packet is 50 bytes.

Definition 3. Duty cycle adjustment rules.

In DSMAC, follow the cycle length of SMAC, about 1.4 s, bandwidth is 20kbps.

Therefore, the transmission time required T_{bit} for a byte is

$$T_{bit} = \frac{1}{20 \times 10^3} \times 8 = 0.4ms . \qquad (14)$$

In NS-2, SMAC protocol was specified in the packet up to 1000 *bytes*. In order to facilitate the calculation, it requires all packet sizes are 250 *bytes*, letting time of each packet is approximately $250 \times 0.4ms = 0.1s$.

When ∂ equals to 1, *s*, the number of packet data being sent every second equals to $1000/(250 \times 8) = 0.5$. Then the number of packet data being sent during every period of T_{frame} is 0.7. Thus, the time is 0.07s and the duty ratio *Dutycycle* is

$$Dutycycle = \frac{T_{listen}}{T_{frame}} \times 100\% = \frac{0.07}{1.4} \times 100\% = 5\% . \qquad (15)$$

When ∂ equals to 2, the number of packet data being sent every second equals to 1. Then the number of packet data being sent during every period of T_{frame} is 1.4. Thus, the time is 0.14s and the duty ratio *Dutycycle* is 10%.

From the above, it can be concluded that the duty ratio and packet sending rate are in linear relationship, that is

$$DUTY_{new} = a\partial + b . \qquad (16)$$

Therefore, *a*=*5*. As conflicts are not included in the calculation, the adaptive duty ratio parameters of adjusting mechanism *b* is also set to be 5 considering circumstances of conflicts. Then, the following magnitude comes:

$$DUTY_{new} = 5\partial + 5 . \qquad (17)$$

Set the synchronous timerds *DSMACGeneTime()* after starting the wireless sensor network node wireless sensor network node wireless sensor network node wireless sensor network node, the cycle is T_{SCYCLE}. During every time slot, the timer minus 1, until the timer becomes 0. Then restart timer for the next monitor. During the process, the nodes should be recorded as the number of packet data being sent *totalpackets* in synchronous period.

And work out the packet sending rate ∂ according to the formulas of (12) and (13). After that, adjust the duty ratio to update synchronously in the timer $DSMACCGeneTimer()$ trigger event $DSMAC::setMySched()$ function according to formula (16), in the meanwhile, reset the number of packet data to 0.

The specific implementations are as follows:

Algorithm DSMAC
start $DSMACGeneTimer()$
{
$while(mhGene\_.sched(T_{SCYCLE}))$
{
$if\ (sendpackets)$
$totalpackets$ ++;
}
calculate packet sending rate ∂;
$DSMAC::setMySched()$;
{
$refresh\_duty()$;
{
recalculate $DUTY_{new}$;
$DUTY_{new} = 5\partial + 5$;
update $Dutycycle$;
}
$totalpackets$ = 0;
}
}

```
Algorithm mhGene_.sched()
start mhGene_.sched
{
  while(T_SCYCLE)
  {
    T_SCYCLE --;
  }
  DSMAC :: setMySched();
}
```

Synchronous cycle period being taken as the cycle of timer, it is to prevent that the remaining times are not synchronized among the nodes within the current luster in the synchronous cycle after the node is changing the duty ratio, which leads to the problem in node communication.

Based on previous packet sending rate ∂ of nodes in the synchronous cycle, DSMAC can predict the condition of the load of nodes in the following periods, which contributes to the adjustment of the duty ratio. If the present packet sending rate is high, increasing the duty ratio in linear according to the principle of adjusting the duty ratio in order to solve problems. The problems are as follows: delay increases and throughput decreases, which results from source node's waiting for the destination node waking up from sleep. If the present packet sending rate is low, decrease the duty ratio in linear to decline the interception time, save the energy and raise the utilization of channel and energy efficiency.

In DSMAC protocol, the length of node cycle T_{frame} is fixed, and can adaptively change the interception time T_{listen} according to network load so as to make dynamic adjusting in the duty ratio *Dutycycle*. It solves the problem of contradiction between delay and energy consumption in SMAC protocol.

The interception time of DSMAC protocol needs no active event to adjust, so there is no concern about the problem of early to bed led by T-MAC protocol.

DSMAC has only one state transition in a cycle, solving the problem of excess energy consumption caused by state transition of many times in AC-MAC. Besides, it is simple to accomplish and does not increase in algorithmic complexity. Therefore, DSMAC can achieve the aims of adapting to the change of network load, decrease the delay effectively, increase throughput capacity and use energy efficiently at the same time.

4 The simulation experiment and results analysis

In order to verify the validity of DSMAC, this paper make it, together with original SMAC protocol and IEEE802.11 protocol conduct the simulation experiment in the same network environment, and analyse the results of performance. The simulation tool is NS-2[18], developed by Berkeley University.

Arrange 101 wireless sensor nodes randomly in the scope of 1200×1200m, and number them from 0 to 100.

Form a pair of CBR data stream transmission links respectively between node 1 and 100, node 2 and 99. In order to know the influences towards network performance in different network flow, the starting time of the two CBR data streams differs. The starting time of the first data stream is 50s and the packet sending rate is 1kbps at the start. The packet sending rate increase 1 for every 200s until up to 5kbps. At 1050s, the two data streams starts together, and the packet sending rate increase from 6kbps to 10kbps. The total time of simulation is 2100s. Then, a scene where the load is growing is constituted to demonstrate the relevant performance of DS-MAC mechanism in network with load fluctuation. Parameter setting Parameter settings in parameter setting NS2 are shown in Table 1.

TABLE 1 Simulation Parameter

Simulation Parameter	Parameter Values	Simulation Parameter	Parameter Values
Energy Model	Energy Model	Idle Power	0.36w
Propagation Type	TwoRay Ground	RxPower	0.36w
Initial Energy	10000J	TxPower	0.65w
BandWidth	20kbps	SleepPower	5.0e-5w
Packet Size	250bytes	Transition Power	0.05w
Numbers of node	101	Transition Time	0.0005s
Initial dutycycle	10%	RXThresh_	3.65e-10s

The thesis demonstrates the network simulation to SMAC Protocol, DSMAC and IEEE802.11 Protocol. Next will be the contrastive analysis of network throughput, the efficiency of network, the average network time-delay and packet loss probability under the situation of the growing of load in the increasing of simulation time.

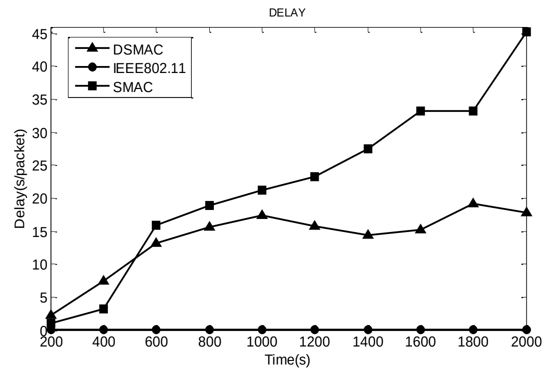

FIGURE 4 The comparison of Network Time-delay of Three MAC Protocols

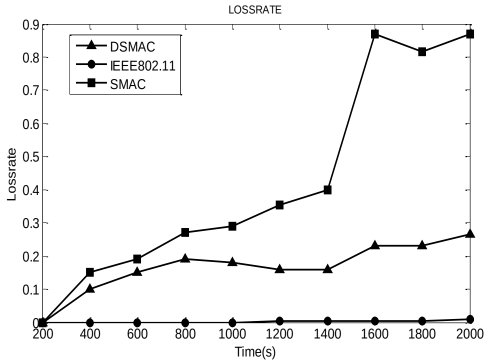

FIGURE 5 The comparison of Packet Loss Probability of Three MAC Protocols

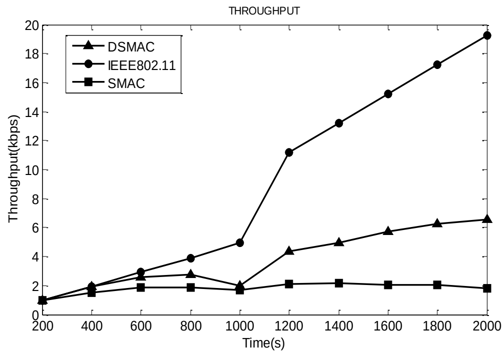

FIGURE 6 The Comparison of Throughput of Three MAC Protocols

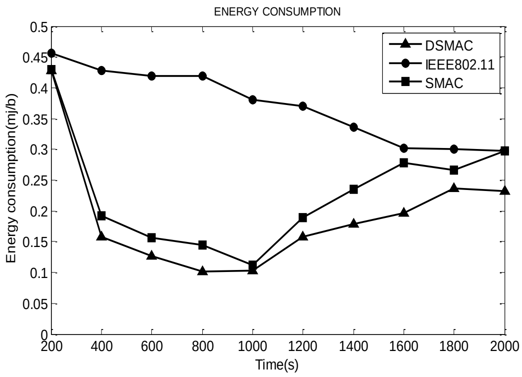

FIGURE 7 The Comparison of Energy Consumption of Three MAC Protocols

From Figure 4 and Figure 5, it can be seen that in the whole process of simulation, the average of time-delay and packet loss probability of IEEE802.11 keep in a low level (approximately to 0). Without the intercept mechanism of sleep cycle, the node is always in intercept condition. If data reception or transmission is needed, the wake-up of node is unnecessary, thus the average of time-delay is in minimum. The average time-delay and packet loss probability of SMAC Protocol are in remarkable increasing tendency, which results from that with the continuous activation of high package delivery, the efficiency of package delivery of the whole network is also increasing and more and more data package will complete transmission in 10% of fixed space, leading to the originating code waiting for the wake-up of destination code and the fierce network competition in serious collision as well as the remarkable increase of the average time-delay and packet loss probability of the whole network. After the utilization of DS-MAC Protocol in which the regulatory mechanism is based on the network traffic control, because the node can accumulate the duty ratio according to state of the data package delivery. When the number of package is increasing, the node can increase its duty ratio as well as the intercept time, making the time-delay and packet loss probability of network highly improved.

The Figure 6 illustrates network throughput of the IEEE802.11DCF, which is always in intercept condition, is very large in unit time. Because the SMAC Protocol take the fixed Duty Ratio Mechanism, when the network flow becomes lager, many groups wait in line, the intercept cycle of node, which wants to transmit the group, cannot adjust itself roundly and the re-transmission will increase after collision, making the throughput stays at the relatively low level. Through the supervision of packet delivery, the DS-MAC Protocol can adjust the duty ration of node according to the change of network flow to improve the network throughput and secure the coal monitor work.

As can be seen from Figure 7, IEEE802.11, SMAC DSMAC bit and high energy consumption in the initial phase, which is the initial stage because only one data stream and a low transmission rate CBR, during which time most of the nodes in the no data transmission is in idle listening state. Around 1000s, SMAC bit consumption to a minimum, and then as the load increases, the node duty cycle is fixed, fierce competition caused large amounts of data packet retransmission, while the source node needs to wait for the destination node wakes up from sleep, lead to networks a tendency to increase the energy consumption. Use the dynamic adjustment of the duty cycle of DS-MAC protocol throughout the simulation stage, the bit consumption of energy is always lower than SMAC. DS-MAC protocol node contract rate increases with increasing duty cycle, although more time to be active, but at the same time significantly improve latency and throughput in the network environment, real-time monitoring of coal node protection work and effectiveness.

5 Conclusions

WSN will be introduced in monitoring forest resources to build a comprehensive, real-time environmental monitoring system. We made an in-depth research and improvement and proposed DS-MAC for the MAC layer technology of WSN to be more suitable to the forest resources monitoring system. DS-MAC protocol has positive significance for forestry internet of things, which is based on WSN.

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