A Medium Access Mechanism to Reduce Transmission Delay in Ubiquitous Sensor Network

Myungsub Lee[1] and Changhyeon Park[2]

[1] *Department of Computer Technology,*
Yeungnam College of Science and Technology
#170, Hyeonchung-no, Nam-gu, Daegu 705-703, Korea
[2] *Department of Computer Engineering, Yeungnam University*
#214-1, Daedong, Gyeongsan, Gyeongbuk 712-749, Korea.
skydream@ync.ac.kr, park@yu.ac.kr

Abstract

This paper presents a more efficient method for medium access in a real-time ubiquitous sensor network. To reduce the latency for the delivery of event data from sensor nodes, a fixed-size contention window with a non-uniform probability distribution of transmitting in each slot is selected. Through a simulation using ns-2, a widely used network simulation package, it is shown that the proposed method can reduce the latency considerably as compared to conventional IEEE 802.11 MAC protocols for a sensor network with up to 256 nodes. It is also shown that the proposed MAC scheme realizes a latency similar to that realized by a decentralized CSMA-based MAC protocol for real-time ubiquitous sensor networks that are sensitive to latency.

Keywords: *Sensor Network, Contention Window, CSMA/CA, DCF, MAC*

1. Introduction

This paper thoroughly analyzes the operating mechanism and characteristics of ubiquitous sensor networks from the viewpoint of developing a more suitable MAC protocol. One of the most important issues in sensor networks is improving the battery life; in fact, several researches have focused on this issue over the last few years [1-4].

This paper focuses on designing a method that can effectively decrease the data transmission delay in a sensor network to the greatest extent possible. This is realized by developing a new MAC protocol by taking into account the three issues listed above. It is demonstrated that with a suitably modeled and simulated sensor network, the proposed protocol reduces the energy consumption of wireless sensors and effectively improves the performance of real-time data transmission. In wireless sensor networks, the amount of initially generated report data is generally quite less, and therefore, the initial slots selected at this time are in a low-contention state. As a result, hardly any collisions occur between slots, and the network latency is low. Considering the abovementioned factors, the MAC protocol proposed in this research differs from conventional ones in the following respects. The contention window size is regularly optimized so as to minimize the latency. In addition, the geometric probability distribution is specifically designed to replace the uniform probability distribution that is conventionally used in order to differentiate the selection probability during the process of selecting the transmission slot [5-7].

The remainder of this paper is organized as follows. Section 2 describes the operating mechanism of the proposed protocol. Section 3 presents a comparison of the performance of a

MAC protocol for conventional sensor networks and the proposed MAC protocol for ubiquitous sensor networks via a simulation. Finally, Section 4 discusses the conclusion and mentions future objectives.

2. Proposed MAC Protocol

This paper proposes a method that differentiates the probability distribution for selecting a slot. The fundamental concept for solving this problem is that not only is the number of collisions reduced to the greatest extent possible but also the probability of selecting a slot in order to minimize the back-off time is relatively increased depending on the location in the contention window.

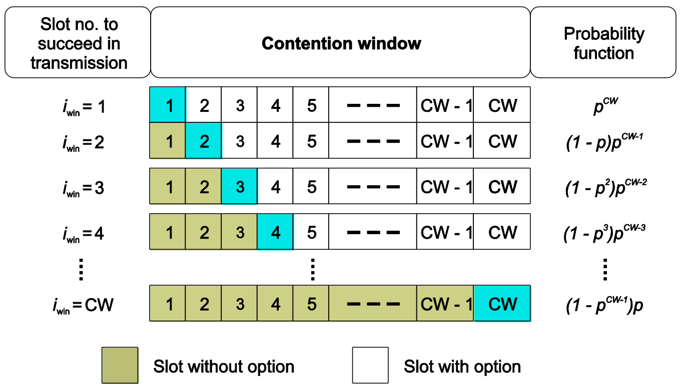

Figure 1. Probability of selecting a slot to minimize contention between nodes

As shown in Figure 1, if an arbitrary slot succeeds in transmitting in the contention window used for back-off, slots in the preceding locations should never be selected. In other words, the probability distribution function must be designed such that only those slots that are located after the slot that has successfully transmitted can be intentionally selected. The probability distribution function of such a property can be derived by multiplying the probability with which preceding slots cannot be selected by that with which succeeding slots can be selected based on an arbitrary slot for all slots. In order to maintain such an optimum selection method, if the probability distribution function is derived using the probability with which preceding slots are not selected and that with which succeeding slots are selected based on an arbitrary slot, it could be said that the probability $f(i)$with which each sensor node selects the *i_th* slot within the range of the contention window follows a geometric distribution with a parameter p, and therefore, the probability mass function can be given by the following equation.

$$f(i) = \begin{cases} (1 - p^{i-1})p^{CW-i+1}, & i = 1, \cdots, CW \\ 0 & , otherwise \end{cases} \tag{1}$$

Here, p is a distribution parameter that indirectly represents the probability that the slot is empty; this parameter is determined by the number of active nodes (N). Here, calculate the probability S_i with which the *i_th* slot is selected through a virtual decision process. The selection probability at the *i_th* slot is the highest when $N_i = N_1$, and N_i has the property that it is constantly reduced from N_1 to 1 as the stages proceed. Therefore, when N_i is relatively large and S_i is small, the probability with which a sensor only selects the *i_th* slot in the condition in which all the slots prior to this slot are not empty can be given as follows.

$$N_i S_i (1 - S_i)^{N_i - 1} \cong N_i S_i e^{-N_i S_i} \tag{2}$$

If $N_i S_i$ is assumed to be constant in the above equation, the probability with which the *i_th* slot is selected gradually decreases as we proceed toward the last slot. In other words, in order to efficiently deal with several nodes (*N*) that are competing to access the medium using a small contention window that has a fixed size, it is necessary to select a scheme in which the number of nodes accessing the medium reduces at a constant rate (Δ).

$$\frac{N_{i+1}}{N_i} = \Delta \;\; (0 < \Delta < 1) \tag{3}$$

The following condition is satisfied if $p = \Delta$ in equations (1) and (3).

$$N_i S_i \cong N_{i+1} S_{i+1} \tag{4}$$

Here, if it is considered that each sensor independently selects a slot and the selected slots compete continuously until the sensor that selects the slot with the smallest number succeeds in transmitting through the back-off process, the probability of selecting a slot for each sensor can be derived from equation (1) as follows.

$$\frac{S_i}{S_{i+1}} = \frac{(1 - p^{i-1}) p^{CW-i}}{(1 - p^{i}) p^{CW-i}} \cdot p \approx p \tag{5}$$

This could be developed for the slots before *CW_th* by the following equation.

$$\frac{S_1}{S_2} \cdot \frac{S_2}{S_3} \cdot \cdots \cdot \frac{S_{CW-1}}{S_{CW}} = p^{CW-1} \tag{6}$$

The result given below can finally be obtained by applying this equation to equation (4) and perform the following procedure.

$$\frac{N_1}{N_2} \cdot \frac{N_2}{N_3} \cdot \cdots \cdot \frac{N_{CW}}{N_{CW-1}} = p^{CW-1} \qquad \therefore \frac{N_{CW}}{N_1} = p^{CW-1} \tag{7}$$

As mentioned above, if it is established that $N_{cw-1} = 1$ for the *CW_th* slot to be selected by only an active sensor, then $1/N_1 = p^{cw-1}$. This is finally given by the equation below.

$$\therefore \; p = N_1^{\frac{-1}{CW-1}} \qquad (0 < p < 1) \tag{8}$$

Then, if it is assumed that $N = N_1$ using equation (8), the optimum probability of selecting a slot, *p*, can be calculated. In other words, if a medium is accessed by using a contention window having 32 slots in a network consisting of 256 sensor nodes, the value of *p* is determined to be approximately 0.8.

3. Simulation Results

The experiment compared the total delay time of the DPSMAC protocol redesigned under the $p = 0.8$ condition when the number of contention slots is 32 with those in the SMAC and MACAW protocols [5-8]. The performance evaluation to measure the delay time and throughput was carried out around 20 times on average after setting different random initial values in a condition in which RTS/CTS was deactivated and the data packet of the sensor nodes was set to have a size of 40 bytes.

3.1 Packet Throughput of Proposed DPSMAC Protocol

First, an experiment was carried out to measure the packet throughputs of the proposed scheme, SMAC, and MACAW, after saturating the wireless medium by varying the network load. In addition, in order to show that the proposed protocol functions normally even in an event-driven network environment, the experiment modeled the constant bit rate (CBR) flows that were simultaneously generated by 32 sending nodes in an ad-hoc steady state network environment, and the packet throughputs were measured.

Fig. 2 shows that the packet throughput of the proposed protocol is superior to those of the other MAC protocols being compared as the CBR traffic is increased.

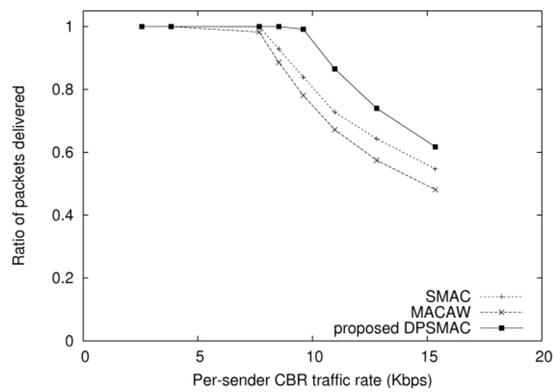

Figure 2. Packet transmission rates of sensor nodes for CBR traffic

First, in the proposed protocol, it might be known that packets collide to a comparatively lesser extent, and the location of a slot that succeeds one that transmits data in the contention window is moved toward the first half of the contention window due to the optimization of the slot selection probability distribution despite the increase in the number of sensors participating in the transmission. Such a fact can generally be considered to result in a reduction in bandwidth concentration when a transmission medium is accessed.

3.2 Transmission Delay Time of Proposed DPSMAC Protocol

An experiment was carried out to measure the transmission delay time of the proposed protocol for an event load generated at constant intervals. Then, the delay caused by the software system installed on the sensor node or the deviation caused by the electronic properties of the sensors is considered to the greatest extent possible in order to more accurately measure the variations in the delay time. In order to reflect this, the experiment added a random time of 0~1ms to the time at which each sensor sent its own event information.

The result of the transmission delay time measured in the experiment depending on the change in the number of sensor nodes is shown in Figure 3.

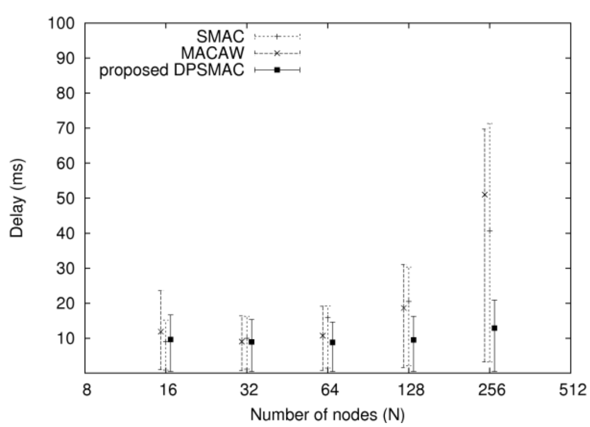

Fig. 3. Transmission delay times depending on number of sensor nodes

In Figure 3, after arranging the packets sent from each sensor node by the order of arrival at the base station in terms of the percentile, the transmission delay time of the packets is respectively extracted at the first, middle, and last 90% locations to obtain the bottom, middle, and top points of the error bar, respectively.

The bottom of the error bar indicates that the minimum contention window size of SMAC and BMAC is sufficiently large to quickly solve the contention problem between nodes when there exist only a few sensors; however, it can be inferred that their contention window size should be continuously increased in advance as the number of sensors is increased in order to realize successful initial data transmission.

On the other hand, it can be confirmed that the proposed protocol requires constant time to solve the contention problem because the contention window size is fixed irrespective of the number of sensor nodes. In addition, the proposed protocol exhibits improved performance in that the total delay time required for data transmission for all sensor nodes is independent of the number of sensor nodes. Although the result measured the total transmission delay time when the sensor nodes were sending data, it is demonstrated that the proposed protocol maintains a performance that is at least equal to those of other contention-based MAC protocols for sensor networks.

4. Conclusion

The proposed MAC protocol is highly adaptable in that it can constantly maintain the transmission rate to the greatest extent possible even if the environment changes frequently and unexpectedly. The main concept of the proposed protocol is that the probability of selecting a slot is fundamentally differentiated to choose the distribution function with a geometrical probability that increases depending on the slot's location in order to select a slot located at the front part if possible when the sensor nodes select the transmission slot in a contention window. In addition, whereas most conventional CSMA/CA based MAC protocols exploit a variable contention window technique, the proposed protocol exploits a fixed-size contention window to reduce the delay time.

References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A survey on sensor networks", IEEE Communications Magazine, 40(8), 102–116 **(2002)**.

[2] I. Demirkol, C. Ersoy, C and F. Alagöz, "MAC protocols for wireless sensor networks: a survey", IEEE Communications Magazine, 44, 115–121 **(2005)**.

[3] A. Abu-El Humos, "Low latency and energy efficient MAC protocols for wireless sensor networks", Ph.D. Dissertation, Florida Atlantic University, Boca Raton, Florida **(2005)**.

[4] B.-S. Kim, S.-W. Han and H.-Y. Ahn, "Link Adaptive MAC protocol for Wi-Fi, The institute of webcasting internet and telecommunication", pp. 69-74 **(2009)** June.

[5] C.-B. Kim and N.-I. Kim, "An Efficient Multi-Channel MAC Protocol for Cognitive Ad-hoc Networks with Idle Nodes Assistance", The institute of webcasting internet and telecommunication, (**2011)** August, pp. 53-60.

[6] J. Polastre, J. Hill and D. Culler, "Versatile low power media access for wireless sensor networks", in: Proceedings of the Second ACM Conference on Embedded Networked Sensor Systems (SenSys), **(2004)** November, pp. 95–107, Baltimore, MD, USA.

[7] W. Ye, J. Heidemann and D. Estrin, "Medium Access Control with coordinated adaptive sleeping for wireless sensor networks", IEEE/ACM Transactions on Networking, 12(3) **(2004)** June , pp. 493–506.

[8] B.-J. Park, H.-S. Yoo and S.-H. Kim, "Performance Analysis of Enhanced MAC Protocol to Improve Utilization in Multimedia Service", The institute of webcasting internet and telecommunication, **(2009)** October, pp. 15-21.