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Research Article

A Differential Probability Selection MAC Protocol Considering Energy Consumption in Wireless Sensor Networks

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In the sensor network using distributed coordination function (DCF) of carrier sense multiple access/collision avoidance (CSMA/CA), sensor nodes have to necessarily compete with others for medium access and service, as the scale of network is increased. Under this situation, many nodes are to collide with each other, and hence this situation finally leads to overall increase of transmission delay which gives rise to the power consumption. This paper presents a differential probability selection MAC (DPSMAC) protocol which is efficient for medium access in the real-time sensor networks. The presented DPSMAC protocol is similar to the conventional CSMA/CA protocols, except that it does not use a time-varying contention window in which a node randomly selects a transmission slot. The DPSMAC adopts the fixed-size contention window with a nonuniform probability distribution in which each slot is selected by the differential probability distribution. The simulation using ns-2, a widely used network simulation package, gives that the proposed method can reduce the latency considerably as compared to the conventional IEEE 802.11 MAC protocols for a sensor network with up to 256 nodes. It also shows that the proposed scheme can realize the latency similar to that realized by the decentralized CSMA-based MAC protocol for real-time sensor networks that are sensitive to latency.

1. Introduction

In the wireless sensor networks, multiple nodes have to share a channel to transmit data, and thus the nodes wishing to transmit their data necessarily compete with others to access the channel. Therefore, the medium access control (MAC) protocol, which is commonly used in the network environment to provide the channel access control mechanisms, is essential for arbitrating the competition problem. This paper intensively analyzes the operating mechanism and characteristics of the wireless sensor networks from the viewpoint of developing more suitable MAC protocol. One of the most important issues in the wireless sensor networks is to improve the battery life. Several researches have focused on this issue over the last few years [1–4].

The MAC protocol for the wireless sensor networks differs from the conventional MAC protocols in the following respects.

(i) Most sensor nodes operate by the event-driven mechanism and compete with other nodes to share a transmission channel.

(ii) Because all sensor nodes do not simultaneously respond to an event, the number of responding nodes in the sensor network is time variant.

(iii) Frequent occurrence of transmission delays increases the energy consumption of sensor nodes and coincidentally reduces the overall performance of the sensor network.

This paper focuses on designing a method that can effectively decrease the data transmission delay in a wireless sensor network to the greatest extent possible. This can be realized by developing a new MAC protocol by taking into account the three respects listed above. The demonstration using the suitably modeled and simulated wireless sensor network gives that the proposed protocol reduces the energy consumption of sensor nodes and effectively improves the performance of real-time data transmission.

When several nodes (N) that are requested to transmit sensing data by the base station are concurrently competing to occupy the transmission channel, the nodes attempt to transmit the requested data (R) to the destination node by avoiding collisions to the greatest extent possible. Whereas the conventional MAC protocols solve this problem by optimizing the throughput for the case in which all the nodes transmit the report data ($R = N$), the MAC protocol proposed in this paper realizes optimized performance of the wireless sensor networks for the case in which only some nodes transmit the report data ($R < N$). Each node in the conventional carrier sense multiple access (CSMA) protocol chooses a slot randomly based on the probability of the uniform distribution in the current contention window (CW) in order to perform the back-off process, which decreases the value of the chosen slot every constant time; the node finally transmits data when this value becomes zero. This method can effectively prevent collisions; however, if the number of nodes is very high, the collisions start to occur between nodes. In such a situation, the network cannot function normally because unavoidable transmission delays are caused.

In the wireless sensor networks, the amount of initially generated report data is generally quite less, and thus the initial slots selected at this time are in a low-contention state. As a result, the possibility of collision between slots can be decreased significantly and thus the network latency becomes low. Considering the above-mentioned factors, the MAC protocol proposed in this paper 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 in order to differentiate the selection probability during the process of selecting the transmission slot.

The remainder of this paper is organized as follows. Section 2 presents a brief review of the related works. Section 3 describes the operating mechanism of the proposed protocol. Section 4 gives a comparison of the performance of a MAC protocol for the conventional sensor networks and the proposed MAC protocol for the wireless sensor networks via a simulation. Finally, Section 5 gives the conclusion and mentions further researches.

2. Related Works

This chapter describes the mechanism of the conventional CSMA/CA-based MAC protocol used in wireless sensor networks. The IEEE 802.11 specifications define the following medium access control methods in the MAC sublayer: distributed coordination function (DCF) scheme; point coordination function (PCF) scheme; and hybrid coordination function (HCF), a hybrid of the DCF and PCF schemes [5]. The DCF scheme is the fundamental MAC method used in IEEE 802.11; it provides a contention-based service with a random back-off algorithm. In contrast, the PCF scheme is used less commonly; it manages channel sharing for nodes using a polling technique through an arbitrator such as an access point (AP).

The random back-off algorithm used in the DCF scheme reduces the value of a slot selected for transmission every constant time interval and starts the transmission when the value becomes zero. Therefore, because the probability of competing nodes being concentrated in the first half of a contention window after sufficient time has passed is high, the probability of a collision for slots having a small value that are located in the first half of the contention window is relatively greater than that of slots having a large value that are located in the second half. In other words, nodes that are performing the back-off procedure are already assigned slots in the previous phase; nodes that should be reassigned slots in the current phase cancel the back-off procedure due to a collision in the previous phase; and the nodes that newly start the back-off procedure to newly request a service in the current phase are relatively concentrated in the first half of a contention window, leading to the occurrence of excessive contention with time. Because of this disadvantage, the back-off algorithm of the conventional DCF scheme results in a decrease in the overall throughput, and the transmission delay of packets increased. To overcome this problem, this paper proposes an efficient probability to select a slot; it is then shown that the proposed mechanism can be more effectively adapted to real-time wireless sensor networks.

2.1. Random Back-off Time in DCF. The DCF scheme requires a station that wants to transmit data to listen to the transmission medium for a distributed interframe space (DIFS) interval; the DIFS interval is the medium's minimum idle time. The contention window appears after a frame has been sent and a DIFS has passed; the window is then divided into several slots, where the length of a slot (*SlotTime*) depends on the medium, and it becomes shorter with an increase in the speed of the physical layer. The nodes competing for medium access occupy the medium after randomly selecting a slot and waiting for a certain time; at this time, the probability of any node being selected is uniform. Because a slot is randomly selected, the back-off timer generates a delay time of $[random\ (i) \times SlotTime]$, called the random back-off time.

Such a back-off algorithm is used to avoid collisions between nodes in advance in order to minimize the competition between multiple nodes to occupy the medium.

2.2. Contention-Based Access Method Using Back-Off Procedure of DCF. Generally, the MAC protocol data unit (MPDU) of a node that is about to transmit can be sent immediately if the idle state of the medium is greater than one DIFS period under the DCF access environment, as shown in Figure 1.

If the carrier sensing mechanism detects that the medium is in use under such a condition, the size of the contention window is changed by the random back-off algorithm (typically, it becomes twice that in the previous phase); if the time

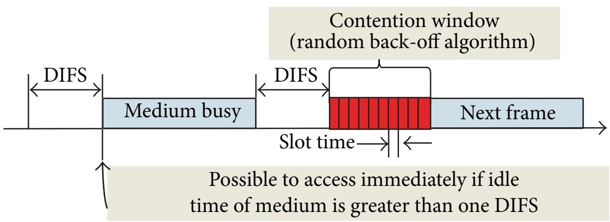

Figure 1: Access method using DCF in IEEE 802.11.

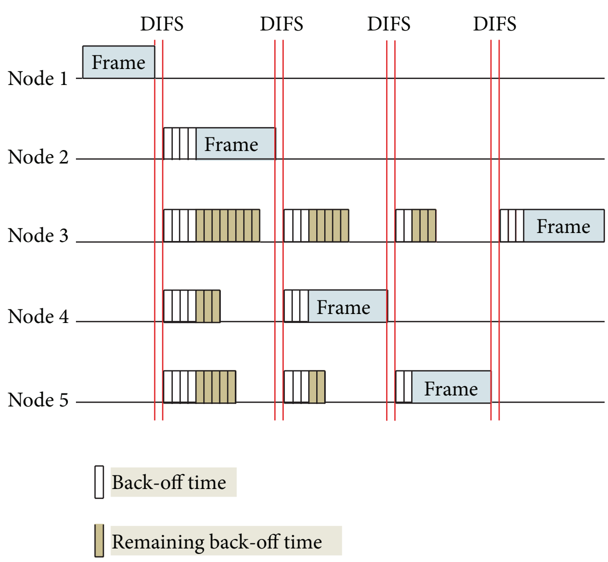

Figure 2: Back-off procedure in DCF.

is insufficient for permitting the transmission of MPDU and an ACK signal although the MPDU is sent or resent, the node postpones the transmission according to the selected random back-off time [6].

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The back-off procedure in the DCF scheme is executed when it is assumed that a sending node has failed to transmit. All back-off slots are generated in the next period when the medium is considered to be ideal for a DIFS period. If it is detected that the medium is in an idle state, the back-off procedure reduces the back-off time by *SlotTime*. On the other hand, the back-off time is maintained and not reduced if it is decided to use the medium in the back-off period. Finally, data transmission is started whenever the back-off timer becomes zero [6].

Figure 2 shows a situation in which five nodes are competing according to the DCF back-off procedure. The minimum back-off time determined by the random back-off algorithm is selected whenever multiple nodes postpone transmission or enter into a random back-off procedure through such a back-off procedure. It is known that the basic condition for gaining medium access and transmitting data is to acquire the minimum back-off time. Therefore, collisions among several competing nodes are avoided to the greatest extent possible by assigning a nonoverlapped back-off time. However, with an increase in the number of competing nodes, the probability of selecting a nonoverlapped back-off time is generally reduced because of the conventional uniform probability distribution.

2.3. Examples of Contention-Based Access Schemes for Sensor Networks. MAC protocols proposed thus far for sensor networks can be classified into a contention-based scheme exploiting CSMA/CA, a schedule-based scheme exploiting TDMA, a scheme exploiting several channels, and a hybrid scheme combining all these schemes. Here, the BMAC and SMAC protocols and their advantages and disadvantages are briefly described.

The BMAC protocol simplifies the protocol's structure to the greatest extent possible by performing control functions such as RTS/CTS and ACK in the upper layer; in addition, it uses the low-power listening (LPL) method that samples a preamble interval longer than the idle interval in order to reduce the power consumption caused by idle listening.

However, the start time for listening is not fixed, because the BMAC protocol does not include its own RTS/CTS function, a function to transmit multiple packets, a function to segment a frame, and a periodic cycle synchronization process. In addition, because it cannot handle hidden terminals, SMAC or TMAC should be added to the upper layer to perform these functions if necessary [7].

The SMAC protocol is a contention-based MAC protocol designed for wireless sensor networks that uses the concept of a slot and a single channel. In addition, it is based on a cycle of sensor nodes that periodically repeat the listening interval and idle intervals, and it additionally requires the virtual clustering task to synchronize the cycle between nodes [8, 9].

SMAC basically divides time into frame units, and each frame is divided into a listening and an idle interval. The latter maintains a state in which the sensor node turns off the power of a wireless node such that it consumes little power, and it reduces the duty cycle of the listening interval to the greatest extent possible in order to reduce the power consumption. However, it is difficult to obtain a trade-off among the transmission rate, delay, and power consumption rate.

The main advantage of the SMAC protocol is that the power consumption caused by idle listening is reduced using the idle mode, and this protocol can be easily implemented. On the other hand, there exist disadvantages in that data packets do not use RTS/CTS, because broadcast packets have a higher probability of colliding, and its efficiency is lowered in a variable traffic load environment due to the prior fixed size of the idle interval and the listening interval [2].

3. Modified MAC Protocol

Whenever a collision occurs between nodes in CSMA-based protocols such as 802.11 [5, 6], BMAC [7], SMAC [8, 9], and MACAW [10], the binary exponential back-off (BEB) method is used to increase the size of the contention window of the colliding nodes twice. In other words, this method increases the size of the contention window of colliding nodes to a size that is sufficiently adapted to the value of the current active nodes in order to minimize collisions between the nodes. However, this method involves the following problems. First, if the number of active nodes (N) that are ready to transmit sensed data increases, say, in a situation in which several sensors simultaneously wait for an idle period, considerable time is required to increase the contention window to a size that is sufficient to accept all of them. Second, if the size of the contention window is increased more than necessary due to previous traffic collisions despite their being only a few active nodes, the bandwidth used in succeeding back-off procedures is dissipated unnecessarily. Therefore, most CSMA protocols can be considered to be inefficient, because they focus only on enabling all active nodes to transfer the data by avoiding collisions.

Therefore, this paper proposes a more efficient dynamic collision avoidance scheme with a contention slot selection system that sets the size of the contention window to the minimum (32 slots) in order to avoid the problems caused in conventional protocols by a collision between nodes; this scheme is based on a nonuniform probability distribution so that it can actively respond to the number of active nodes. In the proposed protocol, the method for selecting a transmission slot differs most significantly from that in conventional CSMA-based wireless MAC protocols in that it minimizes the overlapped selection rate of a slot by fundamentally selecting a slot according to the differentiated probability.

3.1. Problem Involved in Convention Method to Select a Contention Slot. All slots in a contention window are selected with the same probability in the conventional 802.11 MAC protocol. Therefore, in a competing state in which several sensor nodes attempt to access the medium, nodes that are newly participating in the current contention cycle or nodes that are participating again due to a collision in the previous cycle select a slot with the same probability in a contention window having a changed size. Such a slot selection mechanism gradually lowers the selection probability of an empty slot with time despite the change in the size of the contention window.

If the back-off procedure is assumed as shown in Figure 3, first, the slot of the smallest number ($WinSlot_{i-1}$) is assigned a channel to successfully perform data transmission. The remaining slots after this slot are forced to participate again in the next back-off procedure, because they do not complete the back-off procedure; in this case, these slots naturally move to the first half of the contention window. However, because the nodes that are newly participating in the back-off procedure and those that are performing the back-off procedure again due to collision in the previous contention both enter this part of the contention window, the contention inevitably increases. Therefore, if the conventional random scheme that selects a transmission slot among several competing slots according to a uniform probability distribution is used, the probability of collision between nodes can increase considerably.

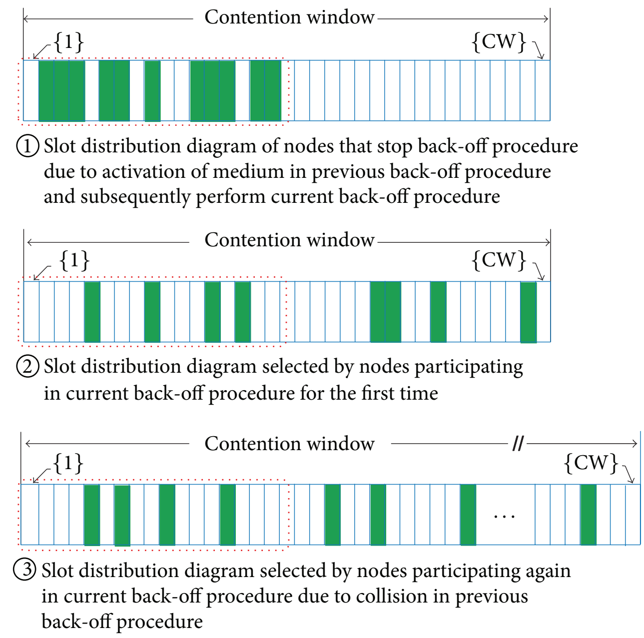

Figure 3: Variation of slot selection probability in general BEB method.

As a result, if a wireless sensor network is intermittently in a high-load state, the overlapped selection rate of competing slots will generally increase due to the limitation of the size of the contention window and the uniform slot selection probability. In particular, the phenomenon in which competing slots are concentrated in the first half of the contention window will be caused as the back-off procedure is proceeding; as a result, collisions will occur frequently between nodes, and this is the most significant cause of the repeated increase in the size of the contention window. Because of such a structural problem, the back-off time of sensor nodes competing to access the medium generally increases, and the transmission delay time and power consumption rate of each sensor rapidly increase; this results in the overall performance of the sensor network deteriorating rapidly.

3.2. Modification of Method to Select Contention Slot. In order to solve the above-mentioned problem, 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.

For this purpose, we first consider a method that finds an empty slot that other sensor nodes do not select in a

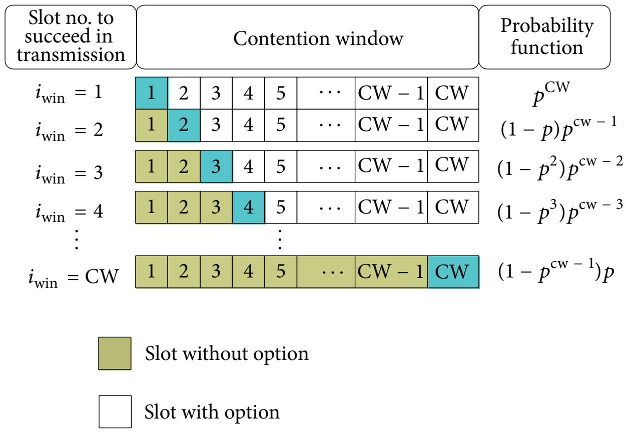

Figure 4: Probability of selecting a slot to minimize contention between nodes.

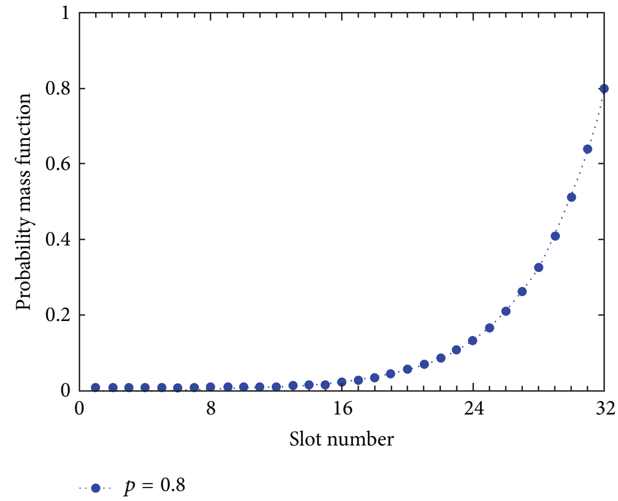

Figure 5: Probability distribution depending on slot number in contention window.

state in which the size of the contention window is fixed. As shown in Figure 4, 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, as shown in Figure 4.

Investigating the designed probability distribution function in greater detail indicates that the best performance can be obtained if the first slot is selected when there is no contention in the current contention window (first stream in figure, $i_{win} = 1$). It may be preferable to select the second slot if the first slot has already been selected by another node. The fact that the ith slot is selected in such a slot selection scheme implies that all the slots located before it have already been selected by other nodes. Therefore, the $(i+1)$th slot is selected in order to transmit data without a collision for the minimum delay time.

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 ith 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:

$$f(i) = \begin{cases} \left(1-p^{i-1}\right) p^{\mathrm{CW}-i+1}, & i = 1, \dots, \mathrm{CW} \\ 0, & \text{otherwise}. \end{cases} \quad (1)$$

As a result, the proposed probability mass function $f(i)$ represents a form that increases geometrically with i in the range of $0 < p < 1$, as shown in Figure 5, implying that the probability with which a certain slot is selected by nodes is relatively higher in the first half of the contention window than in the second half.

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 ith slot is selected through a virtual decision process. Suppose that the number of active nodes at the first stage is N_1 and a node among these selects the first slot. If no node selects the first slot, the second stage reduces N_1 to N_2 and selects the second slot. If the second slot is not continually selected, the third stage decreases N_2 to N_2; in this manner, this process is repeated for each stage. If all slots are not empty in the entire process, it can be assumed that N is finally decreased to N_i.

In summary, the selection probability at the ith 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 ith slot in the condition in which all the slots prior to this slot are not empty can be given as follows:

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

If $N_i S_i$ is assumed to be constant in the above equation, the probability with which the ith slot is selected ($N_i S_i e^{-NiSi}$) 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):

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

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

$$N_i S_i \cong N_{i+1} S_{i+1}. \quad (4)$$

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 (1) as follows:

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

This could be developed for the slots before CW th by the following equation:

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

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

$$\frac{N_1}{N_2} \cdot \frac{N_2}{N_3} \cdot \ldots \cdot \frac{N_{\mathrm{CW}}}{N_{\mathrm{CW}-1}} = p^{\mathrm{CW}-1} \quad \therefore \quad \frac{N_{\mathrm{CW}}}{N_1} = p^{\mathrm{CW}-1}. \tag{7}$$

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

$$\therefore \; p = N_1^{(-1/(\mathrm{CW}-1))} \quad \left(0 < p < 1\right). \tag{8}$$

Then, if it is assumed that $N = N_1$ using (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.

3.3. Comparison of Properties of Modified MAC Protocol. The MAC layer of TinyOS, B-MAC [7], is a type of CSMA protocol that uniformly selects fixed-window-based contention slots. The MAC protocol for the sensor network is designed based on a contention window of fixed size, because relatively good performance is maintained in an actual environment despite the simplicity of the design. On the other hand, there is a disadvantage in that the scalability to a sensor network that is intermittently in a high-load state is low.

MACAW [10], a MAC protocol for wireless LANs, exploits the BEB method but does not share channel state information. This protocol restarts contention for the next transmission, because the size of the contention window is initialized to the minimum value if one of the nodes succeeds in transmitting. However, an overhead is incurred when the medium is accessed, because the sensor nodes competing to access the medium are concentrated in a certain interval and the size of the contention window changes considerably. MACAW solves this problem using a learning method that does not newly reset the size of the contention window and instead decreases the size of the contention window used in the previous contention as a size for the next contention if a packet is successfully transmitted (MILD: multiplicative increase, linear decrease).

The 802.11 specification solves the fairness problem of service using a memory technique. A sensor node participates in a contention, where one of the slots in the contention window is randomly selected with uniform probability, and the value of the selected slot is set in a countdown timer. The countdown is stopped when the medium is busy, and it is continued when the medium is idle. If the value of the countdown timer becomes zero (i.e., the timer expires), the corresponding sensor node starts to transmit. When the transmission is completed, the size of the contention window is initialized to the decided minimum value. As a result, the bandwidth dissipates, because the sensor node needs to determine an adequate size for the contention window.

Table 1: Comparison of contention-based CSMA protocols.

Protocol	Learning technique	Memory technique	Contention window	Probability distribution
802.11	○	×	Variable	Uniform distribution
MACAW	×	○	Variable	Uniform distribution
BMAC, SMAC	×	×	Fixed	Uniform distribution
Proposed DPSMAC	×	×	Fixed	Geometrical distribution

In order to solve such a problem, this paper proposes differential probability of selection MAC (DPSMAC), a novel MAC protocol that exploits the fixed size of a contention window and the random slot selection technique with nonuniform probability. The proposed DPSMAC protocol is advantageous in that it minimizes collisions between nodes and reduces the delay time, and it also maintains the fairness of service relatively and constantly despite the simplicity of the protocol's structure as compared to conventional 802.11 MAC protocols. Table 1 shows a comparison of the properties of contention-based MAC protocols when applied to a wireless sensor network.

4. Simulation Results

In this section, we show the simulation results for the proposed DPSMAC protocol using ns-2 version 2.30, a network simulator. In the simulation, all sensor nodes are considered to be located within a flat area served by a common base station, and a sensor node responding to a certain event among them transmits a small-sized report packet via the base station.

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 [7, 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.

4.1. Packet throughput of Proposed DPSMAC Protocol. First, an experiment was carried out to measure the packet

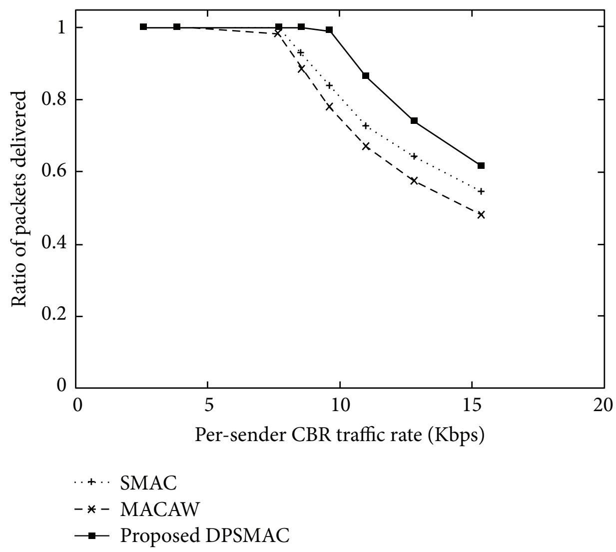

FIGURE 6: Packet transmission rates of sensor nodes for CBR traffic.

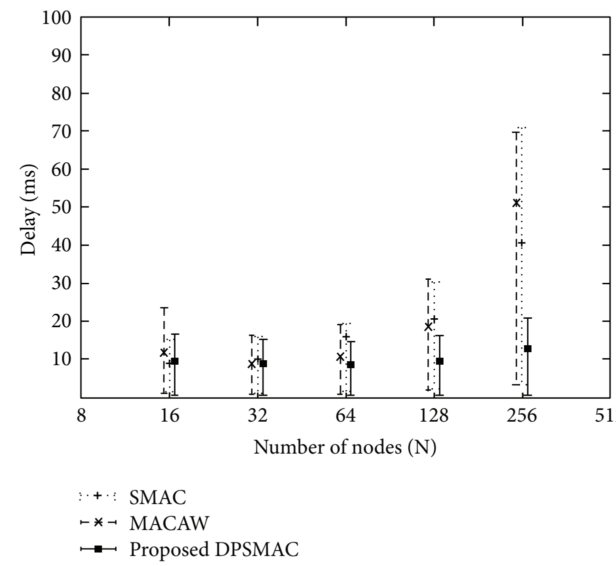

FIGURE 7: Transmission delay times depending on number of sensor nodes.

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.

Figure 6 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. It also indicates that the packet throughput of the protocols reduces slightly as the traffic is increased. It is considered that this reduction is not because of collision between transmitted packets, but because the time required for the back-off procedure is comparatively increased because the slot selected in the contention window is relatively located toward the rear side.

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.

4.2. 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 0~1 ms 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 7.

In Figure 7, 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.

4.3. Fairness Test for Medium Access. Finally, it is considered whether or not the MAC protocol proposed in this paper

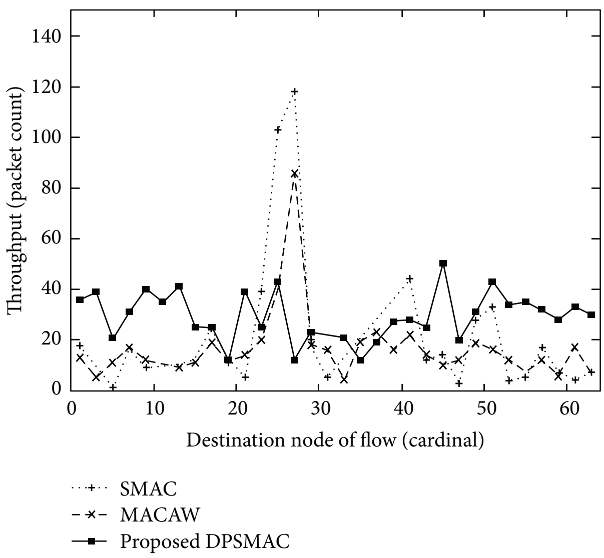

Figure 8: Fairness comparison depending on medium access.

fairly assigns bandwidth for sensor nodes to access the station in order to effectively solve the problem of starvation of service that can occur when some sensor nodes collide. The corresponding experiment simulated an even number of sensor nodes that could perform the role of both traffic sources and sinks within the range of wireless propagation. The size of the data packet of a sensor node was set to 1500 bytes and RTS/CTS activated for data exchange between nodes. To simulate a load environment in which the capacity of the wireless sensor network was exceeded, the congestion of packets transmitted from each sensor was also considered. Figure 8 shows the throughput of each sensor node measured for 10 s.

As shown in the figure, the fact that the throughput of the proposed scheme is not concentrated in any certain sensor node but is generally evenly distributed indicates that it maintains relatively fair medium access as compared to conventional sensor MAC protocols.

Because practical wireless sensor networks contain nodes sending redundant information, it can be considered that the proposed MAC protocol realizes an efficient network that is comparable to the distributed fair scheduling scheme despite the simplicity of the protocol's structure.

5. Conclusion

This paper proposed an efficient medium access method suitable for a large-scale wireless sensor network environment with high spatial density that can enable sensor nodes to effectively transmit the sensor information. The method proposed in this paper employs a modification of the conventional contention window technique. The proposed DPSMAC adopts the fixed-size contention window with a nonuniform probability distribution in which each slot is selected by the differential probability distribution. In the DPSMAC, 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 conventional uniform probability distribution in order to differentiate the selection probability during the process of selecting the transmission slot. Through the simulation using ns-2, we showed that the proposed method can reduce the latency considerably as compared to the conventional IEEE 802.11 MAC protocols for a sensor network with up to 256 nodes. Also the DPSMAC may be highly adaptable in that it can constantly maintain the transmission rate to the greatest extent possible even if the environment is changed frequently and unexpectedly. For the further research, the proposed MAC protocol will be applied to the actual event-based wireless sensor network environment for more practical performance evaluation.

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