A POWER EFFICIENT BACK-OFF SCHEME FOR WIRELESS SENSOR NETWORKS[1]

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ABSTRACT

In this paper, we propose a scheme to save power during the execution of backoff algorithm by avoiding idle listening. Existing MAC protocols for sensor networks reduces energy consumption by introducing an active/sleep duty cycle. But they can't save energy during the execution of backoff algorithm. The propose scheme could further improve the energy efficiency of senor networks MAC protocols. Analytical results show that the propose scheme has significant improvement in energy consumption over traditional backoff algorithm.

KEYWORDS

MAC protocols, backoff algorithm, energy-efficiency, analytical analysis.

1. INTRODUCTION

In recent years, advances in miniaturizing, low power circuit design, and efficient wireless communication chips have enables the development of low-cost, low power, multifunctional sensor nodes. Each sensor node combines sensing, signal processing, low-end processor, and short-range wireless communication facilities in a compact low power system. A sensor network is composed of a large number of sensor nodes that are densely deployed in fields like battlefields, chemical factories and forests. The wireless sensor nodes are usually equipped with limited power source. In some application scenarios, replacement of power resource might be not possible. It is for these reasons that researcher are currently focusing on the design of power-aware protocols and schemes for sensor networks. These schemes include power saving hardware design, power saving topology design and power efficient MAC layer protocols, to name a few [1].

There are a number of MAC layer protocols available for energy efficient sensor networks. Typical examples include S-MAC, T-MAC, and H-MAC protocols [2,3,4]. However, their backoff algorithm is based on IEEE 802.11 MAC protocol, which consumes a good amount of energy. A sensor node remains in idle listening mode while executing the backoff algorithm, which consumes energy and is often not necessary. The slotted CSMA/CA mechanism for a backoff algorithm proposes by IEEE 802.15.4 MAC protocol can be very energy efficient. However, it has some limitations like inflexibility to dense sensor networks and application-tuned parameters [5]. In [6], authors proposed an algorithm to calculate the sleep time for idle listening during the execution of backoff algorithm. Their approach is based on statistical analysis of the channel. But their model missed several practical assumptions as well as it is not flexible for dense sensor networks.

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In this paper, we propose a scheme to save power during the execution of backoff algorithm by avoiding idle listening. The propose scheme is a hybrid approach, which takes the advantage of IEEE 802.11 and IEEE 802.15.4 CSMA/CA schemes. And the propose scheme does not use any additional signaling channel, nor does it need any overhead in the involved protocol. Our numerical analysis and results show that the propose scheme has significant improvement in energy consumption over traditional backoff algorithm.

The rest of the paper is organized as follows. In next section, we present the propose scheme. Later, we present the numerical analysis of the propose scheme. Then, we present the numerical results from our analysis. Finally, we conclude the paper and describe the future evolution of the propose scheme.

2. POWER EFFICIENT BACKOFF SCHEME (PEBS) FOR SENSOR NETWORKS

P-persistent IEEE 802.11 employs a CSMA/CA MAC protocol with p-persistent backoff , referred to as the distributed coordination function (DCF), to access the medium, the details of which have been summarized in [7]. In a typical usage scenario, a contending node spends most of its time to listen the channel, and considerable amount of energy get waste in listening during the backoff period. Therefore the node can be put into sleep in the process of decreasing its backoff time counter (BC), specially, when energy constraint is very tight for sensor networks. In this case, the slotted CSMA/CA mechanism for a backoff algorithm proposes by IEEE 802.15.4 MAC protocol can be very energy efficient. But as we mentioned above it is not suitable for dense nodes, its BC is limited to $2^5 - 1 = 31$ slots (BP), which is too small to reduce the impact of densely deployed senor nodes. In p-persistent IEEE 802.11 protocol, the backoff delay is chosen within an interval $[CW_{\min} \ldots CW_{\max}]$ where $CW_{\min}$ and $CW_{\max}$ are the lowest and highest values of the backoff delay interval, respectively. These limits can be set in the range of [0, 1024], which is quite large to handle the heavy load/dense sensor nodes. However, p-persistent IEEE 802.11 protocol performs Clear Channel Assessment (CCA) operation after every slot, and hence consumes more energy compared to IEEE 802.15.4 slotted/unslotted CSMA/CA mechanism during the backoff period. In this paper, we present a hybrid power efficient backoff schme (PEBS), for sensor networks, and could also be apply to IEEE 802.11 protocol. PEBS is based on IEEE 802.11 and IEEE 802.15.4 CSMA/CA mechanism. Figure 1 presents the flow chart of PEBS.

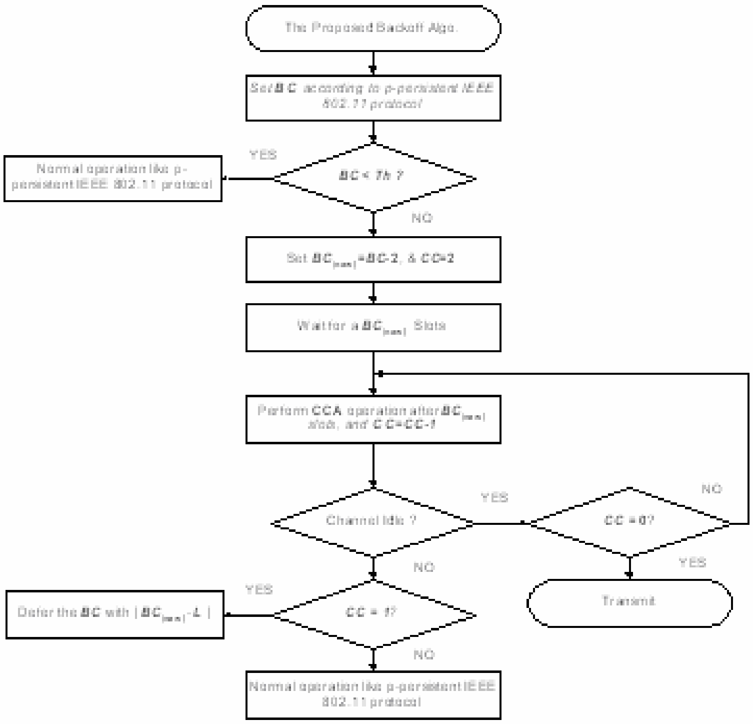

Figure 1 The proposed PEBS

In p-persistent IEEE 802.11, the backoff timer keeps running as long as the channel is sensed idle, paused when data transmission (initiated by other stations) is in progress, and resumed when the channel is sensed idle again for more than DIFS. Other hand, IEEE 802.15.4's backoff timer don't perform any CCA operation during backoff time interval, and CW is re-initialized to $CW_{\min} = 2$ and NB and BE are incremented if channel is sensed busy. Hence, it is not possible for IEEE 802.15.4's backoff mechanism to pause when channel is sensed busy. In this paper, we introduce the parameter L, where L is the average number of slots in the backoff interval in which one or more station starts a transmission attempt, and calculate its value with numerical analysis, which is described under numerical analysis section. With L PEBS defer the BC value to $|BC_{(new)} - L|$ instead of setting new value as in IEEE 802.15.4 backoff mechanism, and hence PEBS can get the advantage of IEEE 802.15.4 power-efficiency with p-persistent IEEE 802.11's backoff mechanism structure. First, the number of backoffs counter (BC) and contention window are initialized according to normal p-persistent IEEE 802.11 protocol. If BC is grater than Threshold Counter value (Th), new BC ($BC_{(new)}$) is calculated and Clear Counter (CC) set to 2, otherwise, BC initializes with old value and follows normal p-persistent IEEE 802.11 operation. It could not be energy–efficient to follow PEBS, for BC< Th condition, and hence Th gives lower bound condition for PEBS. When the new BC expires, the PEBS then performs one CCA operation to assess channel activity. After the first CCA operation, we consider four cases as follows to get the clearer understating of PEBS.

Case 1, If the channel is busy and CC=1:

In this case, if the channel is busy and CC=1, BC is differed and set to $|BC_{(new)} - L|$ for next backoff period.

Case 2, If the channel is idle and CC=1:

In this case, if the channel is sensed as idle, CC is decremented. The CCA is repeated if $CC \neq 0$. This ensures performing two CCA operations to prevent potential collisions of acknowledgement/data frames (For adopting PEBS in IEEE 802.11 backofff algorithm, we need some changes in PEBS for ex. modification in CC for DIFS slots). If the channel is again sensed as idle, the node attempts to transmit.

Case 3, If the channel is busy and CC=0:

In this case, BC follows normal p-persistent IEEE 802.11 operation. By normal operation we mean, a node for each packet will experience I backoff times $\{B_1, B_2, \ldots, B_I\}$ that are sampled in a uniform way in intervals of length $\{CW_1, CW_2, \ldots, CW_I\}$, where I is the number of attempts to successfully transmit a packet.

Case 4, If the channel is idle and CC=0:

In this case, the node attempts to transmit.

3. NUMERICAL ANALYSIS

In this section, we present the numerical analysis of Threshold Counter value (*Th*) and parameter *L*, which is based on the numerical analysis of [8]. First, we calculate the Threshold Counter value (*Th*) in terms of energy spends by a node as

$$Th = 2E_{WS} + 2E_{list}.t_{slop} \quad . \qquad (1)$$

Where E_{WS} and E_{list} are the energy required by the node to switch from sleep to wakeup or wakeup to sleep and listening the channel, respectively. And t_{slot} is a time slot of backoff interval. In PEBS, a node performs CCA as well as switching operation (wakeup-sleep/ sleep-wakeup) for twice, so we multiple each term of (1) by 2. Equation 1 also represents by

$$n.t_{slot} \times E_{list} = 2E_{WS} + 2E_{list}t_{slot} = Th \, . \qquad (2)$$

Where n is the number of slots required to balance the *Th* value. To calculate the value of *L*, we consider a simple definition of the slot utilization (S_U) as derived in [8] and given by

$$S\_U = \frac{Busy\_Slots}{Total\_Slots} \, . \qquad (3)$$

Where $Busy\_Slots$ and $Total\_Slots$ are the average number of busy slots in which one or more nodes start a transmission attempt and the average total number of slots available for transmission in the backoff interval, i.e., the sum of idle and busy slots, respectively. Here, we also represents $Busy\_Slots$ and $Total\_Slots$ by L and $E[B]$ (the average backoff interval), respectively.

Now $E[B]$ is given by

$$E[B] = \frac{(E[CW]-1)}{2} \quad . \tag{4}$$

And $E[CW]$ is give by

$$E[CW] = \frac{2}{p} - 1 \, . \tag{5}$$

Where $E[CW]$ is the average contention window and p is the transmission probability of a node. Now, from (4) and (5),

$$E[B] = \frac{(1-p)}{p} \, . \tag{6}$$

For simplicity, we assume that packet lengths are an integer multiple of the slot length t_{slot}. Furthermore, packet lengths are i.i.d. and geometrically distributed with parameter q. Hence, the average message length is given by

$$\overline{m} = \frac{t_{slot}}{(1-q)} \, . \tag{7}$$

From [8], it is easy to prove that average number of nodes that transmit in a slot (assuming the optimal node’s behaviour) is equal to S_U .

$$M.p = S\_U \, . \tag{8}$$

Where $M.p$ is the function of q , $M.p(q)$, and is derived assuming M active station scheduling their transmission attempts in a slot selected according to a geometric distribution with parameter p, and it is given by

$$M.p(q) = \frac{-1 + \sqrt{1 + 2.l(q)}}{l(q)} \, . \tag{9}$$

Where $l(q)$ is the average length (in slots) of a collision generated by two overlapping transmissions, and it is given by

$$l(q) = \frac{1+2q}{1-q^2} \, . \tag{10}$$

4. NUMERICAL RESULTS

In this section, we present preliminary numerical results based on the numerical analysis presented in the previous section. Figure 2 shows the transmission probability of a node while varying the number of neighbouring nodes. We keep the $q = [0.9, 0.96]$ for data length of 10 and

25 slots, respectively. From figure 2 it is cleared that as data length increases, the transmission probability reduces, and hence we get lower L value. Figure 3 shows the average number of backoff slots while varying the number of neighboring nodes, for different data lengths. Figure 4 shows the average number of busy slots (L) while varying the neighboring nodes, for different data lengths. From figure 4 we can observe that different data lengths have very low/negligible effect on average number of busy slots (L), as there is not much variation in S_U ratio. Figure 2, 3 and 4 are very useful for designing a sensor network, we could choose different optimal parameter from them. Figure 5 shows the aggregate energy consumption of a node while varying number of slots in backoff interval, for traditional (like IEEE 802.11) and the propose backoff schemes. From figure 5 we clearly observe the energy efficiency of PEBS over traditional (old) backoff algorithm, as PEBS avoid the idle listening during the execution of backoff algorithm. However, PEBS could not be energy-efficient when the BC value is below threshold counter value (Th), infact, old and new backoff schemes gives the same energy efficiency.

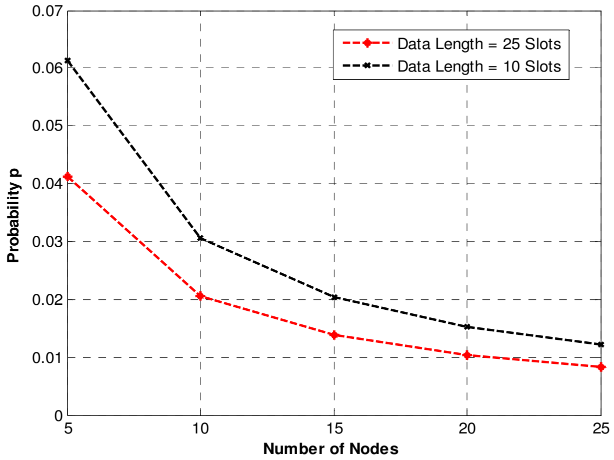

Figure 2 Effect on p while varying the neighboring nodes

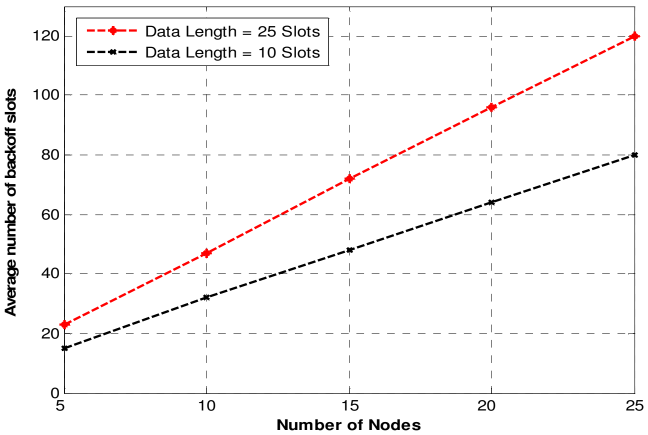

Figure 3 Average number of slots vs. number of neighboring nodes

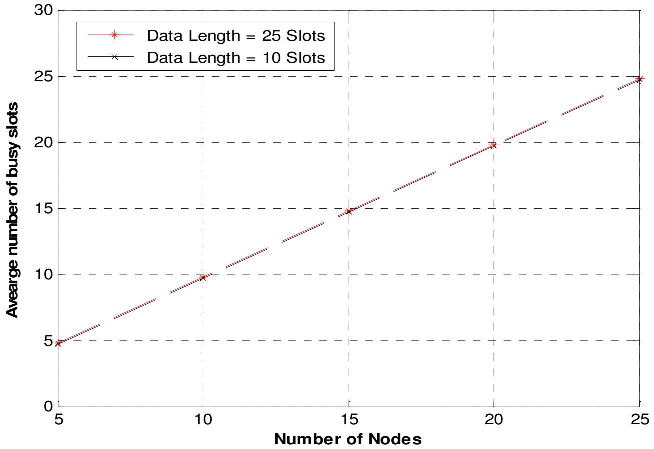

Figure 4 Average numbers of busy slots vs. Number of neighboring nodes

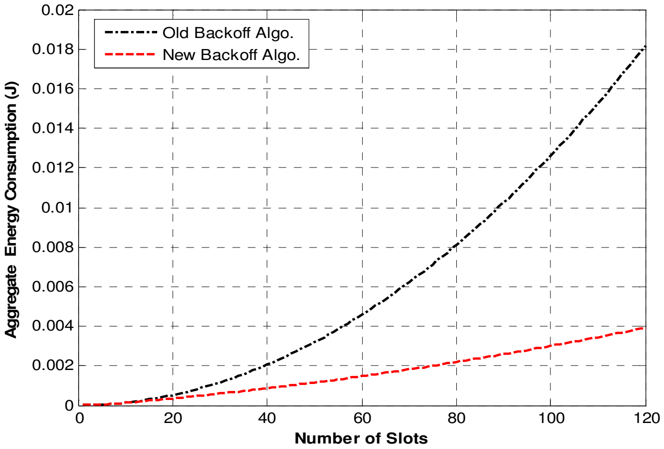

Figure 5 Aggregate energy consumption of a node

5. CONCLUSIONS

In this paper, we propose a Power Efficient Backoff Scheme (PEBS) for sensor networks. The propose scheme is a hybrid approach, which takes the advantage of IEEE 802.11 and IEEE 802.15.4 CSMA/CA schemes. The propose scheme could further improve the energy efficiency of senor networks MAC protocols by avoiding idle listening during the execution of backoff algorithm. Our numerical analysis and results are useful for sensor network designer and also show that the propose scheme has significant improvement in energy consumption over traditional backoff algorithm.

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