Chapter 2
Enhanced Back-Off Technique for IEEE 802.15.4 WSN Standard

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Abstract IEEE 802.15.4 is the standard for Low-rate Wireless Personal Area Networks. The CSMA-CA algorithm used in the standard for channel contention causes performance bottlenecks in certain scenarios. We have conducted a performance evaluation of the back-off algorithm with the help of simulations on star networks and identified two parameters which affect the performance of the algorithm – macMinBE and macMaxBE. Further, we have also proposed an enhanced algorithm which involves these two parameters and improves the performance of the back-off algorithm.

2.1 Introduction

2.1.1 Wireless Sensor Networks

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor and sense physical and environmental conditions [1]. The IEEE 802.15.4 standard aims to provide PHY and MAC layer specifications for ultra low complexity, ultra low cost, ultra low power consumption, and low data rate wireless connectivity among the devices that form a Wireless Personal Area Network.

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2.1.2 CSMA-CA Mechanism

CSMA-CA is used by the network nodes to sense the channel and check whether it is idle or not, before transmission of data [2]. Collisions and packet loss are the major problems faced in such a wireless network. This is where the concept of back-off becomes crucial. Back-off algorithm determines how much time should be spent waiting before transmission, when the channel is busy or after collision. A node which backs off for unnecessarily long periods of time can severely hamper the throughput, cause delay and greater energy consumption. Whereas a node which backs off too soon, will perform as many more Clear Channel Assessments (CCAs), find the channel to be still busy and eventually declare failure to transmit. Hence it is important to choose the right method or algorithm for back-off to improve the performance.

The main factors of the back-off algorithm that affect the network efficiency are, the range of the back-off exponent (BE) value, the number of times CCA is performed before transmission, the strategy used to choose and modify the BE value with every successful transmission or collision and the maximum number of times that the node attempts to transmit a packet.

All devices under a personal area network (PAN) coordinator have their back-off periods aligned with it such that every time a device wishes to transmit data it locates the boundary of the next back-off period and waits for a random number of back-off periods. If the channel is busy, following this random back-off, the device waits for another random number of back-off periods before trying to access the channel again. If it finds the channel to be free, then the device locates the next available back-off boundary and transmits the packet. The CSMA-CA mechanism is not used for acknowledgement and beacon frames.

2.1.3 Existing Variations of CSMA-CA Back-Off Mechanism

Several schemes and modifications have been suggested in order to improve the performance of the standard in terms of throughput, delay, energy efficiency or improving other quality of service attributes. Some of these modifications are specifically for the CSMA-CA contention algorithm and focus on reducing time delay between contentions, delays caused due to collisions and improving energy efficiency of the algorithm.

The authors in [3] have proposed two schemes to improve the back-off algorithm so as to better utilize CCAs which are rather energy intensive. Hence, these mechanisms are used to adjust the BE value based on CCA results and packet transmission and in turn also shift the back-off counters to reduce redundant back-offs and CCAs.

In proposed delay mitigation algorithm based on priority [4], the key idea was to reduce the default contention window (CW) value to one for high priority packet. It makes channel access much easier for high priority packets as CCA is performed only once, whereas low priority packets having $CW = 2$ must perform CCA twice. This algorithm greatly reduces delay of a high priority packet.

The state transition back-off scheme in [5] attempts to address the issue of unnecessarily long back-off periods, which reduces the energy efficiency of the mobile stations. When a sensor node first has packet to send, it sets minBE to be 3. After successfully sending each packet, it decreases minBE by 1 until it is 1, if the sensor node still has packet to send. Conversely, it increases minBE by 1, if the sensor node has no data to send in two consecutive superframes, but minBE is limited to be 3.

The dynamic back-off scheme given in [6] proposes a memorized back-off scheme (MBS) along with an exponential weighted moving average (EWMA) approach for dynamic adjustment of the size of the contention window based on the traffic load and the window sizes of the previous successful transmissions. The algorithm outperforms IEEE 802.15.4 during heavy traffic. Though, the authors have solved the problem of collisions due to heavy contention but have not considered the effect of large back-off time between packets.

In the delayed back-off algorithm proposed in [7], different back-offs are allotted to different nodes by the coordinator so as to avoid collision. This is supposed to increase success probability since all the nodes are supposed to finish back-off at different times. However, there is a need to perform 3 CCAs in order to avoid collision between packets using the standard CSMA/CA algorithm and the delayed back-off algorithm. CCA is an energy-intensive activity.

A novel QoS CSMA/CA based on a Gaussian back-off time was proposed in [8] in which the characteristics of Gaussian random variable is changed after every back-off. Further packets of different priorities are supported by maintaining different Gaussian characteristics for each. This scheme is said to be easily adoptable without much change to the standard. However, if the appropriate Gaussian characteristics are not selected, then the collision probability might increase.

We find that the main factors of the back-off algorithm that affect the network efficiency are, the range of the BE value, the number of times CCA is performed before transmission, the strategy used to choose and modify the BE value with every successful transmission or collision and the maximum number of times that the node attempts to transmit a packet. However there is no single modification that is feasible and suitable for all scenarios. While some tackle the problem of collision control, others address the problem of unnecessarily long delays between contentions and yet others require support at the hardware level and are suitable for certain types of applications.

2.2 Enhanced Algorithm

We have conducted a performance evaluation of the back-off algorithm with the help of simulations on star networks and identified two parameters which affect the performance of the algorithm – macMinBE and macMaxBE. Further, we have also proposed an enhanced algorithm which involves these two parameters and improves the performance of the back-off algorithm.

2.2.1 Motivation

Wireless sensor networks are used in several critical time-bound applications, where data from every node (mote) is crucial and the failure to receive data from all nodes can cause severe performance loss or in certain cases potential damage. Some of these applications include forest fire detection, sensing leaks in nuclear reactors, biomedical sensing and other such fault intolerant applications. Our focus has been on primarily such high data rate applications and a mechanism to minimize loss of packets due to excessive contention and collision.

According to the IEEE 802.15.4 standard, the BE value is set to a value in the range of two variables macMinBE and macMaxBE. The macMaxBE (henceforth referred to as simply maxBE) value indicates the maximum value of the back-off exponent BE. The macMinBE (henceforth referred to as simply minBE) value is the minimum value of the back-off exponent. In order to enhance the performance of the back-off algorithm, we suggest that these values be flexible and dynamic to changes. Further, these values must be changed by keeping in mind the maximum number of back-offs allowed for a particular packet. This value is decided by the maxCSMABackoffs parameter. By default, this value is set to 5. Hence, the parameters must be changed such that the range of values for BE has exactly 5 values. It is important that a different BE value be chosen in all the attempts by a node to send a packet so that the probability of choosing a different wait time each time increases.

Changes to these parameters must be performed according to some agenda on how to handle failures and successes in transmissions. Our agenda involves giving priority to the failures in transmission. Nodes which face the problem of consecutive failures in transmission, will choose a BE value from a range such that it needs to spend lesser time backing off (waiting) and instead trying more often to get the channel.

2.2.2 Suggested Changes

The following changes were proposed based on our analysis.

- Initially minBE is set at 2 and maxBE is set at 6 for every node.
- Following two consecutive failed transmissions for each node, minBE and maxBE are both decremented by 1. This is so that any node with two consecutive failed transmissions is allowed to contest for the channel more vigorously.
- Following two consecutive successful transmissions, the minBE and maxBE values are incremented so that it contests for the channel less vigorously, thereby allowing other nodes to successfully transmit their packets.
- The minimum limit for minBE is set at 1 and maximum value at 3(default value in standard CSMA-CA). The minBE value is the first value BE assumes in order to wait while attempting to transmit a packet. A wait is essential to keep the collision probability under check. A minimum value of 1 is chosen so that in

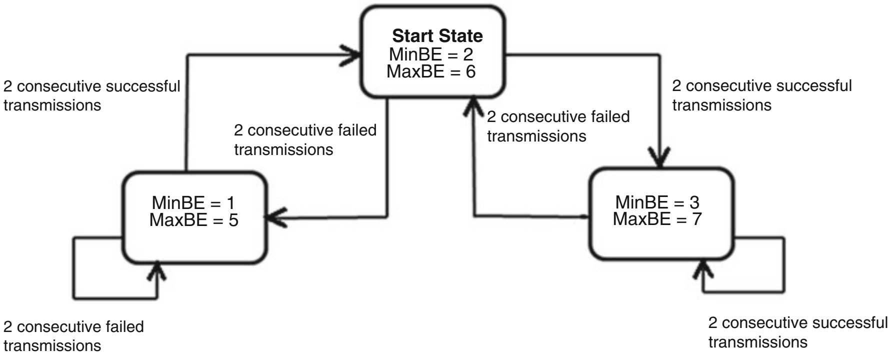

Fig. 2.1 The proposed state transition based back-off algorithm

case of repeated failed transmissions, a node performs a short wait before sending a packet. Similarly, an upper limit of minBE at 3 is put in place so that if a node has been successful in its past few transmissions, its minBE does not increase to a number such that it has to wait unnecessarily long periods to transmit a packet. The limits on the maxBE value have been put accordingly so that a node can have its BE value assume a different value each time it finds the channel to be busy. Hence the minimum limit for maxBE value is set at 5 and maximum limit at 7.

Figure 2.1 depicts the changes we have proposed in this algorithm.

2.2.3 *Simulation Results*

NS2 (Network Simulator 2) is a network simulation software that allows us to design Wireless Sensor Networks and analyze the performance of the network. We used the NS2 simulator to perform our experiments and modified the simulator's implementation of the CSMA-CA algorithm in order to observe the performance of our enhanced algorithm (Table 2.1).

Our main intention with this scheme was to address the issue of the number of packets dropped due to successive collisions. The standard uses the maxCSMABackoffs parameter to determine the maximum number of retries allowed for a packet. The following graph shows the number of packets that are dropped on reaching maxCSMABackoffs.

Figure 2.2 shows how the number of packets dropped on reaching maxCSMABackoffs varies for both the standard algorithm and the enhanced algorithm as the number of nodes are increased. As seen, the number of packets dropped is far lesser, by about 55.6 %, for our enhanced algorithm when compared to the standard and this trend is observed for all the variations in the number of nodes.

Table 2.1 Simulation parameters – star topology

Traffic type	CBR traffic
Packet size	70 bytes
Data interval	0.6 s
Number of nodes	3–15
Routing type	AODV
Topology	Star topology
Antenna type	Omni-directional antenna

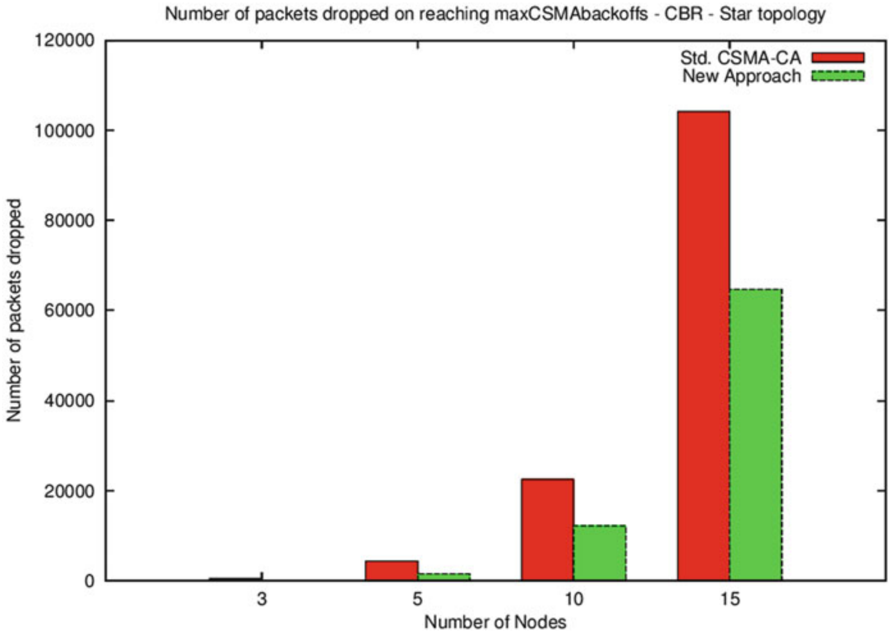

Fig. 2.2 Number of packets dropped versus number of nodes

The other network parameters used to test the performance of the enhanced algorithm against the standard are end-to-end delay, throughput and the number of packets sent.

Figure 2.3 shows the variation of end-to-end delay versus number of nodes. End-to-end delay is calculated as the average amount of time the packets take to reach from the sensor nodes to the PAN coordinator. As the number of nodes increases the difference between the end-to-end delays of the standard algorithm and the enhanced algorithm becomes more prominent. The enhanced algorithm tends to exhibit lesser end-to-end delay compared to the standard algorithm in all cases. The average decrease in the End-to-End delay is about 12 % when compared to standard back-off algorithm.

Figure 2.4 shows how the number of sent packets vary for both the algorithms as the number of nodes is increased. The dynamism and the flexibility in the enhanced

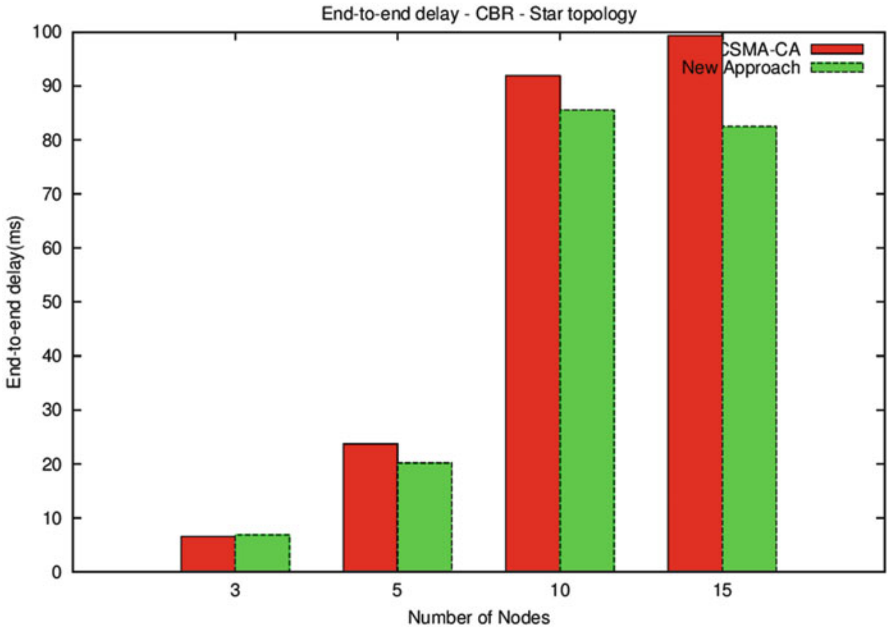

Fig. 2.3 End-to-end delay (ms) versus number of nodes

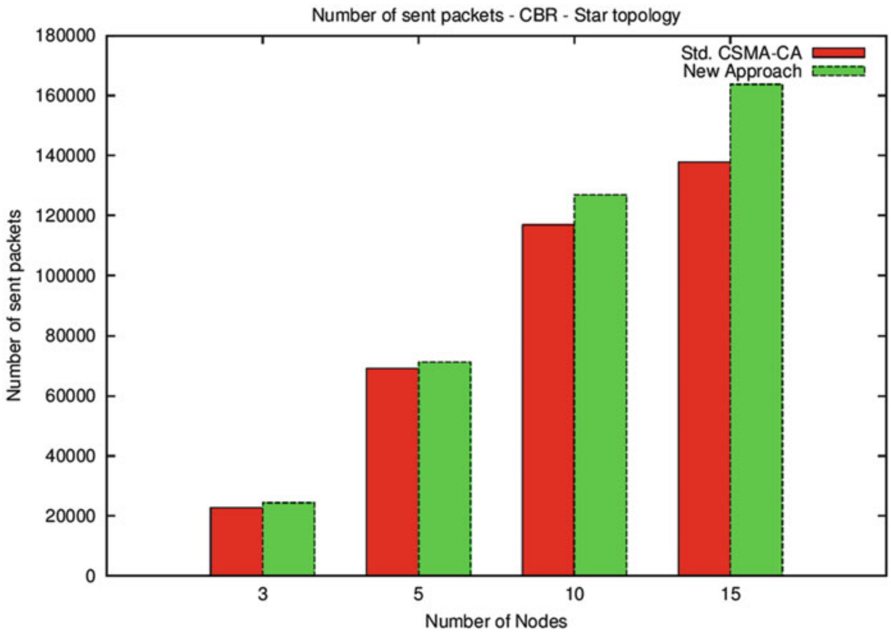

Fig. 2.4 Number of sent packets versus number of nodes

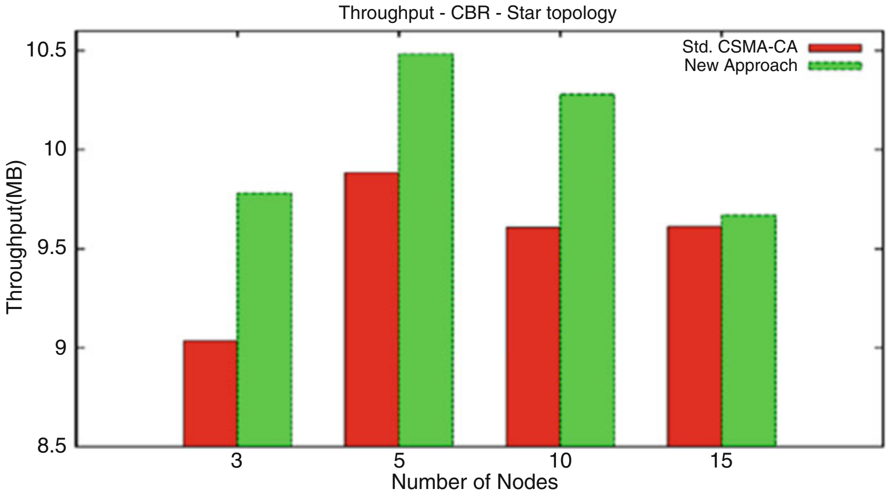

Fig. 2.5 Throughput versus number of nodes

scheme are helpful in sending a greater number of packets in a limited time period. We have observed an increase of 9.47 % on an average in the number of packets sent using the enhanced algorithm.

Throughput is a direct measure of how many packets are received at the PAN coordinator. Figure 2.5 indicates the performance of the algorithms in terms of throughput. The throughput of the network is more when using the enhanced scheme amounting to an increase 5.24 % when compared to the standard CSMA-CA back-off algorithm, however, the receiving capability of the PAN coordinator poses a limitation on the amount of packets received as the number of nodes is increased.

2.3 Conclusion

The enhanced scheme effectively adjusts the range from which the BE value is chosen keeping in mind the failures and successes in packet transmissions. The proposed algorithm was, however, found to be more suitable for all high density traffic in a wireless sensor network. In high-data rate scenarios, where nodes are sending packets often, failure in transmission of packets is a common problem. It reduces the end-to-end delay which helps in critical real time systems with time bound performance requirements, for example, in a forest fire detection scenario, or wild life monitoring scenarios. The throughput is also fairly high compared to the CSMA-CA algorithm which signifies that the rate at which the sink receives the data is also improving. We have observed a significant increase in the number of sent packets. The only limiting factor is the receiving capability of the sink. Moreover we also observe a decrease in the number of packets dropped because of exceeding the NB or number of back-offs. This shows that the channel contention itself is performing better in these scenarios than in CSMA-CA algorithms. Future work in this area involves analyzing the energy efficiency of this algorithm against the standard CSMA-CA algorithm.

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