Efficient Beacon Collision Avoidance Mechanism Using Neighbor Tables at MAC Layer

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Abstract. NLC-BOP algorithm is proposed for the beacon collision problem in IEEE802.15.4. Beacon collision is divided into direct conflict and indirect conflict and NLC-BOP algorithm is used to solve these two kinds of beacon collision problems. NLC-BOP algorithm based on BOP uses neighbor tables to solve beacon collision. The coordinator establishes 1 hop and 2 hop neighbor tables at MAC layer and allocates the beacon transmitting order for other coordinators at the same time. Finally, the size of the BOPL can be estimated and we make assumption and processing for the coordinator of death and isolation. The simulation results indicate that new algorithm compared with the original algorithm greatly reduces energy consumption, packet loss rate. In the case of guaranteeing delay, it improves the throughput.

Keywords: IEEE802.15.4 · MAC · Beacon collision · Neighbor tables

1 Introduction

There are beacon mode and non-beacon mode of MAC layer in IEEE802.15.4. In the non-beacon mode, nodes are always active in the network. However, in the beacon mode, coordinators periodically transmit beacon frame and make nodes synchronization. A personal area network (PAN) is composed of multiple nodes and the coordinator transmits a packet to another coordinator through direct links or multiple hops. If the node is not succeed to access the channel, the node will discard the packet and then a new packet is generated in the next superframe [1]. Beacon collision will be caused when multiple devices almost join piconet at the same time. Each device selects its own beacon slot in order to avoid collision. Choosing improper beacon slot leads to repeated collision and then increases time overhead achieving devices synchronism. When the device is not able to avoid repeated collision, it is difficult for the device to join piconet, even in deadlocks [2].

In IEEE802.11, using RTS (request to send) and CTS (clear to send) avoids beacon collision. There are no RTS/CTS in IEEE802.15.4. In order to overcome the problem, TG4b groups provide two beacon scheduling techniques: superframe duration scheduling (SDS) and beacon only period (BOP). [3, 4] allows the network to dynamically modify the BOP length for better adapting the dynamic network. The

J.-H. Lee and S. Pack (Eds.): QShine 2016, LNICST 199, pp. 396–405, 2017.
DOI: 10.1007/978-3-319-60717-7_39

results also show the throughput ratio of the dynamic BOPL is better than BOP. There is much technology to solve the beacon collision through multiple channels. [5] presents a fixed channel management mechanism which divides network into several sub network. Each sub network occupies a channel and using BOP beacon scheduling technique in the internal of sub network. [6] proposes a receiver tracking contention (RTC) scheme, which achieves high throughput by allowing the receivers to assist for channel contention. In RTC, link is the basic unit for channel access contention. Specifically, transmitter is used to contend for the channel and receiver is used to announce the potential collision. [7] presents VFA, namely virtual frame aggregation, to achieve high coordination efficiency by amortizing the overhead over multiple transmissions. [8] aims at mitigating the so-called Funneling Effect for S-MAC, particularly by improving the throughput and fairness of S-MAC.

There never will be beacon collision in a single star topology of the IEEE802.15.4. But there is more or less beacon conflict in mesh network [9]. In multihop mesh network, each node periodically transmits its beacon and then monitors whether there are others or their activities by checking beacon. As a result, losing beacon message cause low efficiency and high cost [10, 11]. When multiple nodes send a beacon to the same place at almost the same time, there will be continuous collision which blocks the normal operation of the network. Nodes can not join the piconet. When the beacon information contains key information, such as network and time parameters, the topology of the network will be destroyed [12].

Researchers have proposed a variety of methods to solve the beacon collision problem. An adaptive beacon scheduling with power control in cluster-tree network is presented [13]. The scheduling mechanism assumes that LR-WPANS (low-rate wireless personal networks area technology) technology can support environmental monitoring applications in IEEE 802.15.4 standard. Node clustering is a very effective method to manage topology in wireless sensor networks, which can reduce the beacon collision and improve the network lifetime [14]. The author improve the above method by allocating the accurate beacon sequence values and superframe values for coordinator cluster, coordinators PAN and device nodes and determining the exact time of the PAN and coordinator nodes beacon transmission. Game theoretical models are used in the wireless medium access control [15]. To avoid the beacon collision, every coordinator decides its time to send beacon frame according its transmission probability and power level. A new beacon slot technique (TBoPS) is presented in cluster tree topology [16]. In order to avoid the beacon collision in the large-scale IEEE 802.15.4 cluster tree Zig Bee network, a beacon scheduling using utilization-aware hybrid is presented [17]. This method can improve the scheduling performance of the target network by better using the transmission medium and avoid the inter-clusters collision. Simple time conversion scheme is presented based on IEEE 802.15.4 [18, 19]. SDS and BOP basic beacon scheduling mechanisms are analyzed [20].

In the article, NLC-BOP algorithm is proposed to avoid beacon collision without using multichannel. Analyzing nature of the direct and indirect conflict, NLC-BOP tries its best to use neighbor tables to avoid occurrence of beacon collision. The remaining part of the paper is organized as follows. The details of our algorithm are described in Sect. 2, where we propose a beacon collision improvement method. The simulation results of experiments and performance evaluation are presented in Sect. 3. We conclude our algorithm in the last section.

2 NLC-BOP Algorithm

In view of the two kinds of conflict, this paper puts forward the NLC-BOP (Neighbor List Control–Beacon Only Period) algorithm which adopts coordinator neighbor table to solve beacon conflict based on the BOP. NLC - BOP algorithm includes three parts. The first part is set up the coordinator neighbor list and beacon order allocation and the second part chooses BOPL length. The third part processes the dead or isolated coordinators.

2.1 Neighbor Table Establishment and Order Allocation

To simplify the narrative language, we set the following variables. 1 hop coordinator neighbor table, 2 hops coordinator neighbor table, beacon order which a coordinator sends in BOP.

Steps:

(1) PAN coordinator establishes the main network and the order is 1.
(2) After a new coordinator joins the network, the first broadcast around the hello beacon. Once A coordinator receives the hello beacon, the address of the new coordinator joins one, and then putting one in beacon A to broadcast.
(3) If the new coordinator continues receiving the beacon frames from around B, it first looks at whether address of the beacon B in their two. If in two, the address is removed from the two and added to one. If not in the two, it adds the address to the one directly. At the same time processing the one of beacon B one, it adds the address which does not exist in one to two.
(4) If there will be other coordinators around the new coordinator, it will perform step 3 repeatedly. The new coordinator argues that it has received all beacon frames which sent by other coordinators after t seconds.
(5) New coordinators view their own one and two and choose a minimum order that has not yet appeared as the value of the order.
(6) The new coordinator sends beacon frames with its beacon order; around 1 hop coordinator perfects its own one after receiving beacon frames and transmits the information to the peripheral coordinators at the same time in order to make some coordinators perfect the two of themselves.
(7) Network building repeats steps 2 to 6 until the entire network is steady.

Now analyzing t value of the above 4 steps. We assume that there is no beacon conflict or missing during building tables. Communication range of nodes is r, the density of nodes deploy is ρ and receiving a beacon frame average every θ seconds.

So the number of node is *num* as (1) within the scope of the new communication coordinator.

$$num = \rho \pi r^2 \quad (1)$$

The minimum value of t is $t_{\min}$, such as (2) formula (2).

$$t_{\min} = num * \theta \quad (2)$$

Due to the assumptions, there is no beacon conflict and missing during building tables, so the actual value of t is much larger than $t_{\min}$. According to the (1) and (2), we get $t \propto \rho$ and $t \propto r^2$. So deployment and power control of the nappropriate nodes will lead t increasing sharply and it is harmful for the establishment of the neighbor tables.

2.2 BOPL Length Estimation

How to estimate the BOPL approximation and as far as possible to expand the length of the CAP are an important purpose of NLC-BOP. In Fig. 4, this article assumes that beacon length is the fixed symbols λ, the time slot between the beacons is the SIFS and 12 symbols are default. So sending a beacon frame need to consume 12 + λ symbols in BOP phase.

Running after a period of time on the Internet, NLC-BOP will assign a beacon order for each coordinator, so there is a maximum of order in this network. Assuming the value is μ.

According to the assumption of values, we can get the minimum value $BOPL_{\min}$ of BOPL that network requires, as shown in the (3).

$$BOPL_{\min} = \mu * (12 + \lambda) \quad (3)$$

And the size of a time slot cycle is *SlotLength*, as shown in the (4).

$$SlotLength = aBaseSlotDuration * 2^{SO} \quad (4)$$

Assuming that the *SO* of network is α, the default value of aBaseSlotDuration is 60. So we rewrite the (4) and get the (5).

$$SlotLength = 60 * 2^{\alpha} \quad (5)$$

According to the (3) and (5), we obtain n time slots at least which meet the needs of the BOPL.

$$n = \left\lceil \frac{BOPL_{\min}}{SlotLength} \right\rceil \quad (6)$$

Through the (6) we infer that the network may occur the following two situations. The first situation: After allocating BOPL, the rest number of symbols is (aNumSuperframeSlots - n) $* 2^{SO} = (16 - n) * 2^{\alpha}$, it still meet the minimum aMin-CAPLength of CAP and the default value is 440 which indicates that the network is normal and do not need to adjust. The second situation: If excessive nodes are deployed densely or at the PHY layer use improper RF power, it will lead to the nodes increase sharply in the neighbor table which needs more beacon order. By (3), BOPL will increase sharply. So after the assignment BOPL, the rest of the activity time slot can't meet the minimum of CAP. At this time we can take measures to increase the value of the SO to expand the network activity time, adjust the duty ratio, control the RF power and reduce the communication range. These measures are not in consideration of this paper, the concreteness can reference literature [3, 5], etc.

According to the Fig. 1 and (6), NLC-BOP selects BOPL whose unit is time slot. So the starting point of CAP should be placed at the beginning of a time slot rather than in the middle. As shown in Fig. 1, the starting of CAP is the point between the end of the second time slot and the start of third time slot. The purpose of NLC-BOP is to make it easier to coordinate each coordinator data transmission. At the same time set aside some time in preparation for later adding new coordinator at any time.

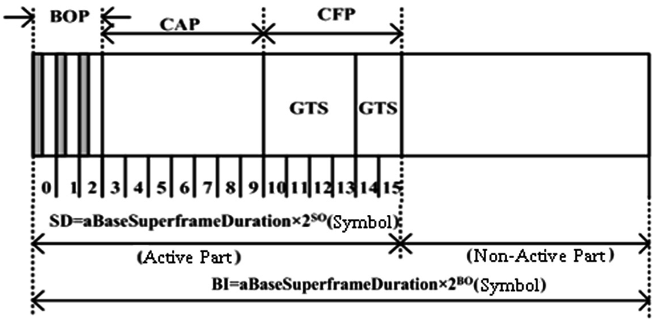

Fig. 1. Starting CAP based on NLC-BOP

According to Fig. 1 and combing the (4) with (6), we conclude how to calculate the values of the BOP, as shown in (7). We assume the node sending beacon order is *order*.

$$postBeaconDelay = N * SlotLength - [order * \lambda + (order - 1) * 12] \tag{7}$$

2.3 Coordinator Death or Isolation

NLC-BOP adds the neighbor tables based on IEEE802.15.4 and modifies the beacon frames. Def_macCAPStarting and def_macSendingBeaconOrder are added to the MAC_PIB, def_phyEnergyMultiple is added to PHY_PIB.

The data structure of the neighbor tables of 1 hop and 2 hop as shown in Table 1. NLC-BOP algorithm process is made the 1 hop neighbor table be loaded to BeaconPayload of beacon frames and is sent out with beacon frames.

Table 1. Neighbour list

Address of nodes	SendingBeaconOrder

A Flag is added to the beacon frames. But in the Flag, the previous two used to distinguish the hello beacon and beacon of death respectively, after six record beacon order of detail drawing 6 in Fig. 4. Specific is shown in Table 2.

Table 2. Structure of flag

Bit:0 l	1	2–7
IsHello	IsDeath	SendingBeaconOrder

According to Ho - j [3], we know that it is enough to use that distribute 16 orders for the network with 40 nodes. SendingBeaconOrder accounts for a total of 6 bits, 64 orders can be allocated which can meet the network that is not serious dense. According to IsHelloand and IsDeath of Table 2, we distinguish these frames: normal beacon frames, hello beacon frames, death beacon frames and beacon frames with sequence. Details as shown in Table 3.

Table 3. Four kind of beacon frame

IsHello l	IsDeath	Type of frame
0	**0**	Normal beacon frames
1	**0**	Hello beacon frames
0 g	**1**	Death beacon frames
1	**1**	Beacon frames with sequence

3 Simulation Experiment and Analysis

The whole network simulation parameters are shown in Table 4. There are three graphs, respectively, the conflict rate chart, the average energy consumption graph, as well as three cases of effective throughput rate chart. Among them, the simulation

Table 4. Parameter of simulation experiment

Simulation parameters	Parameter values
Network size (m2)	500×500
Simulation time (s)	1000
Number of nodes	100
Topological structure	Reticular
Routing protocol	AODV
Packet size (B)	70
Queue length	30
Sending power (mW)	300
Receiving power (mW)	300
Initial energy (J)	1000

analysis of the effective throughput graph can obtain the relationship between the time interval T and BO, SO at the case of that SO was 3 and BO were 3, 4, and 5.

3.1 Conflict Rate Analysis

From Fig. 2, the network in about 100 s, the original algorithm beacon collision immediately increased significantly, while the new algorithm has also increased with slow speed. In 200 s, the highest point which the collision rate of the new algorithm reached only is the half of the conflict rate of the original algorithm. After 200 s to 250 s, the new algorithm has been assigned to the network to send a beacon sequence, resulting in a conflict rate of 300 s after the decline has been reduced, until the maximum simulation time of 1000 s, almost down to 1 points or less. And the original algorithm is still maintained a high rate of conflict, until the end of the simulation is also in a high position. Although the conflict rate of the original algorithm is not more than 20%, but the ratio of the conflict rate, that is, the ratio of the rate of conflict equals that original algorithm conflict rate divides conflict rate of the new algorithm. The result is that the conflict rate ratio was 100%, and finally up to more than 1600%. It can be concluded that the new algorithm can effectively reduce the beacon collision.

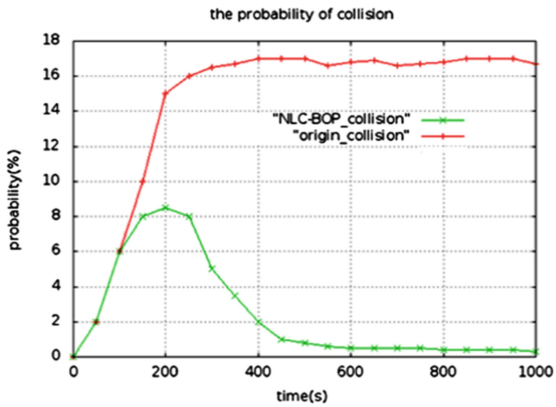

Fig. 2. Probability of collision

3.2 Energy Consumption Analysis

The average energy consumption of the original algorithm in the whole simulation for 1000 s is always stable, and it is in a linear trend. In the first 250 s of simulation, the new algorithm is faster than the original algorithm because of the need to establish the neighbor table and the allocation order. However, between 250 s to 400 s, the speed of energy consumption has eased. In 400 s time, the energy consumption of the algorithm has reached a balance, after the conflict rate of the new algorithm is much smaller than the original algorithm, so the energy consumption continues to decline, as shown in Fig. 3 in 400 s, the trend to maintain a slow rise.

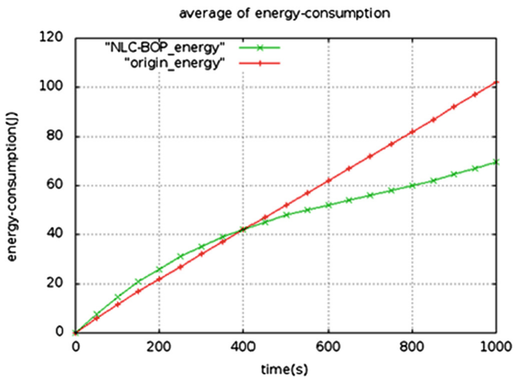

Fig. 3. Average of energy consumption

3.3 Goodput

Figure 4 shows the relationship between the different BO, SO and the sending data packet interval time with new algorithm. The effective throughput rate is directly related to the transmission data packet rate of the whole network simulation node. If the packet is sent too short or too fast at a time, it will cause the buffer queue of the node to be filled quickly, and then the packet will be discarded.

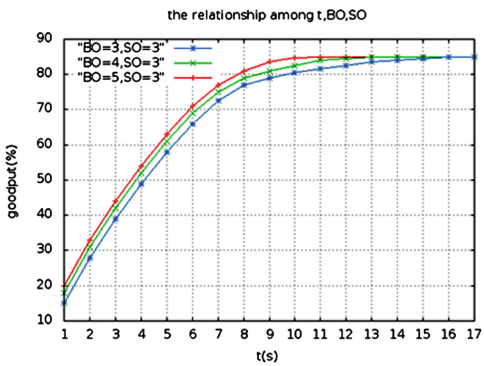

Fig. 4. Relationship among t, BO and SO

4 Conclusion

The paper proposes NLC-BOP algorithm based on IEEE802.15.4 protocol to solve the beacon collision which leads the performance of entire network to drop in the mesh network. At the beginning of the establishment of the network, the coordinators in the MAC layer build 1 hop and 2 hop neighbor tables and allocate the beacon order for the coordinators to avoid the emergence of beacon collision. Then, it estimates the size of

BOPL and deal with dead and isolated coordinators. Simulation results show that the NLC-BOP algorithm can solve the beacon collision problem and make the collision rate of the entire network significantly decrease, while the network life cycle is greatly extended.

Acknowledgment. The work is supported by National Natural Science Foundation and Shanxi Provincial People's Government Jointly Funded Project of China for Coal Base and Low Carbon (No. U1510115), the Qing Lan Project, the China Postdoctoral Science Foundation (No. 2013T60574), the National Natural Science Foundation of China (Grant No. 51404258), and the Natural Science Foundation of Jiangsu Province (no. BK20140202).

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