An Adaptive Grouping Scheme for Avoiding Hidden Node Collision in IEEE 802.15.4 LR-WPAN

Mohammad Irfan Khan and Rakesh Rathi

Abstract IEEE 802.15.4 standard is proficient to execute with low-power for short distance in low-rate wireless personal area networks. For reducing the consumption of power in IEEE 802.15.4, slotted CSMA/CA protocol is used. However, the performance of LR-WPAN still degrades due to the hidden node problem (HNP). This paper proposed a simple and efficient grouping strategy to mitigate the HNP. The main concept is to gather the hidden information for every node, and then assign the nodes in the group on the basis of collected information. This scheme splits the superframe of IEEE 802.15.4 into numerous subperiod without overlapping each other. Simulation results shows that the given scheme not only mitigate the collision but also improves the transmission capabilities.

Keywords Superframe · Collision · Hidden Node Problem

1 Introduction

In twentieth century, wireless sensor networks (WSNs) have get attention from areas like industries and academics. With the evolution of sensor network technologies, nowadays WSNs are developed for different application domain like home automation, industrial automation, and health care. The existing applications rely on IEEE 802.15.4 specification to operate in low rate for short distance communication [1].

WSNs are comprised of several scattered nodes along a gateway which collects the information from nodes [2]. Moreover, sensor nodes are developed by different vendors. So there will be a lack of communication between them. IEEE 802.15.4 is the one candidate through which sensor nodes of different vendor can communicate.

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In WSNs, there will be a situation in which two different nodes that are invisible of each other can communicate with a common visible node at a particular time interval. So, in this situation, collision occurs and this collision is known as hidden node collision (HNC).

Busy tone mechanism [2] is the popular solution for avoiding the hidden node problem (HNP). This mechanism requires two channels: one is data channel and second is control channel. When the channel is idle, node can transmit data on data channel; if a channel is busy, receiving node send a busy tone on a control channel. The problem with that mechanism is that it requires an additional channel. So this mechanism is not considered to be the ideal solution for avoiding HNP.

Zigzag decoding [3] is another approach for mitigating the HNP. In this mechanism, a buffer is required on the coordinator side. Moreover, it also requires lots of processing to recover the collided data. Hence, it not considered as a good idea to address the issue of HNP.

Review of [4, 5] states that HNP is also avoid through grouping techniques. In these techniques, node forms the group on the basis of hidden relationship. When the new node wants to join the group, all the groups must be rearranged, hence, it requires lots of power for collecting the hidden information, when a new coming node wants to join the group.

Fast recovery [6] and H-NAMe [7] are other approaches for resolving the HNP. In fast recovery mechanism, nodes may turn off their transceiver for saving the energy. While remaining in the sleeping mode, there is a probability of missing some information. On the other hand, in H-NAMe, the process of gathering the hidden information could result in large overhead. Therefore these two approaches will not be adapted to resolve the HNP.

This paper proposed a simple grouping scheme based on polling process. The basic idea is that nodes in the same group could not be hidden with each other. In this process, coordinator sends a request message toward every nodes. Nodes that failed to acknowledge the request will be consider as hidden node, after that coordinator assign the groups for the nodes on the basis of collected information. The proposed scheme is described in four major phases: the first one is hidden node relationship, the second is grouping of nodes and the final phase is bandwidth allocation.

The remaining paper is organized in the following manner. Section 2 gives the overview of IEEE 802.15.4, Sect. 3 briefly explain the grouping strategy, Sect. 4 explains the simulation results and Sect. 5 concluded this paper.

2 IEEE 802.15.4 Overview

An IEEE 802.15.4 device globally operates at 2.4 GHz with data rate of 250 kb/s [8]. The transmission range lies in between 10 to 100 m. Devices under this standard should be categorized as full function device (FFD) and reduced function device (RFD). The first active FFD will become the coordinator. The Medium access control (MAC) of LR-WPANs also support two topologies, star and peer-to-peer topologies. In this article, we only discussed star topology in which communication is maintained between nodes and a central controller. IEEE 802.15.4 networks either operates in beacon-enabled mode or in non-beacon-enabled mode. In beacon-enabled mode, a central device should be considered as coordinator. Moreover, devices should transmit data by using superframe structure as shown in Fig. 1. The entire superframe is mainly partitioned into two parts that are active period and inactive period. The active period is further partitioned into contention access period (CAP) and contention free period (CFP). The entire superframe is bounded between beacon frames. Note that, CAP begins from the end of the beacon frame and stops at the start of CFP. Slotted CSMA/CA is applied in the CAP portion of the active period for medium access. However, for real time service, CFP is reserved. CFP is made up of several guaranteed time slots (GTS).

At most seven FFD may demand the coordinator to assign the GTS for real time service. Moreover, the entire active portion of superframe is partitioned into 16 equally sized time slot and GTS must occupy more than one time slot. The total duration of active period is determined by superframe duration (SD). The value of SD is controlled by system parameter that is superframe order (SO). While the time between two consecutive beacon is specified by beacon interval (BI), the value of BI is controlled by beacon order (BO) parameter.

SD and BI are calculated as follows

$$
\begin{aligned}
SD &= aBaseSuperFrameDuration \times 2^{SO} \\
&= aNumSuperFrameDuration \times 2^{SO} \\
&= 16 \times 60 \times 2^{S0}(symbols) \\
&= 960 \times 2^{SO}(symbols)
\end{aligned}
$$

$$
\begin{aligned}
BI &= aBaseSuperFrameDuration \times 2^{BO} \\
&= 960 \times 2^{BO}(symbols) \\
& 0 \le SO \le BO \le 14
\end{aligned}
$$

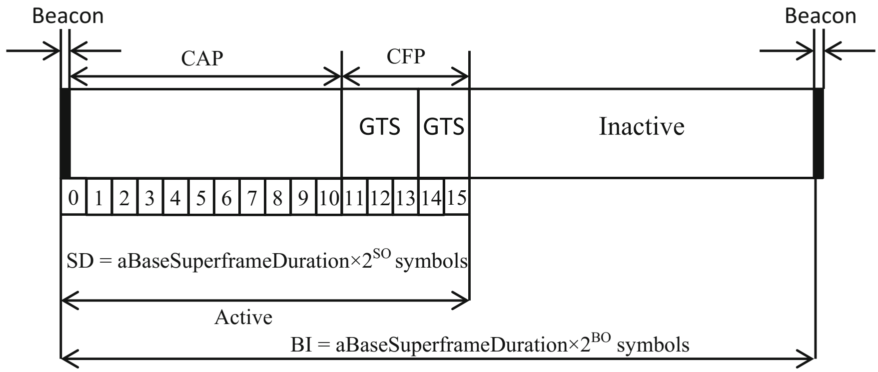


Fig. 1 Superframe structure of IEEE 802.15.4

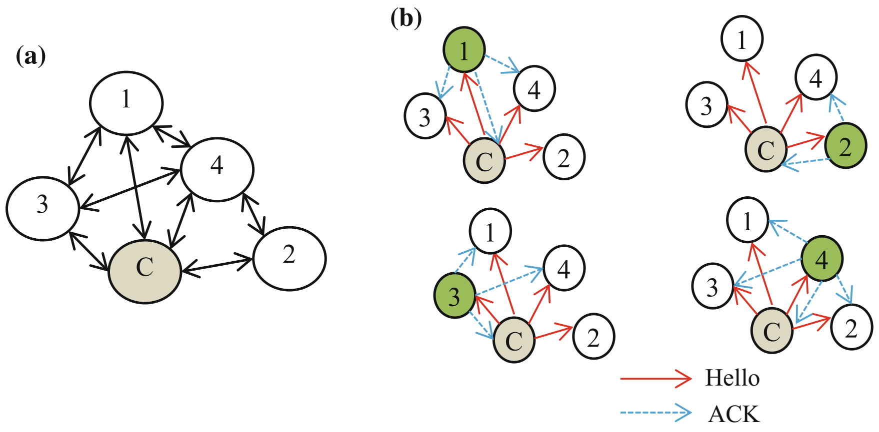
The BI may optionally include inactive period, nodes can turn off their transceiver for saving the power.

3 Grouping Scheme

The given scheme fundamentally consist of three phases: collection of hidden node information, group engagement, and group access period notification

A. Hidden Node Information Collection

Once the situation of hidden node is identified by the coordinator, it is ready to gather the hidden information among nodes; we consider four nodes and a coordinator as an example in Fig. 2a. In this figure, bidirectional link between nodes indicate that information is exchanged between them. In the given topology, hidden node situation still exists, as node 2 is not directly connected with nodes 1 and 3. Now coordinator broadcast a request message for all the nodes. Note that request



(c)

Node	Hidden nodes
1	2
2	1, 3
3	2
4	No

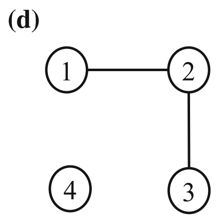


Fig. 2 Procedure of collecting hidden node information. **a** Topology, **b** Polling process, **c** Record of Hidden node, **d** Graph of hidden node

message is attached with beacon frame, to order all the nodes in the ingoing superframe to become active, and waits for the data frame with empty payload and this data frame is known as polling frame shown in Fig. 2b. Those nodes that do not acknowledge the polling frame are considered to be the hidden node by coordinator.

After the successful completion of polling process, all the nodes contain the information of their hidden nodes. Now coordinator broadcast a reporting message for all the nodes to return their hidden information with the help of polling approach. After receiving the hidden information, coordinator builds a hidden node graph. Figure 2d shows the hidden node graph

B. The Node Grouping

Once the construction of hidden node graph is completed, coordinator allocates the nodes in the group on the basis of collected hidden information. Note that directly connected node in the graph could not be resided in the same group. For better utilization of channel, grouping scheme must full fill two conditions: (1) number of nodes is balanced among groups and (2) to cover the entire network, minimal number of group must be used.

The solution of reducing the group looks like Hamiltonian subgraph problem [9]. It has been prove as NP-complete problem. In this article, we propose a simple algorithm to balance the nodes among groups.

Assume the set of nodes be *V*, except the coordinator in LR-WPAN. The given algorithm starts picking a node with largest degree from set *V* and form the group. The picked node is erased from set *V*. Now the node with second highest degree is examined from set *V* whether having an edge toward the node of that already formed the group or not. If not, it can be assign in the formed group, else algorithm marked this node and passes away. Similarly, all the remaining nodes in the topology are examined on the basis of their degree. Once all the node in set *V* is marked, given algorithm starts assigning the second group with procedure that already described. This process continues until the set *V* will become empty. The grouping algorithm is described below.

Grouping Algorithm [5]

Input: Given a hidden node graph $G = (V,E)$;

Output: Group sets $S_1, S_2, \ldots, S_g$; $(g \leq k)$

$k = 1$; // group index

While $|V| > 0$ **do**

Select node v from V of the highest degree;

Build group set $S_k = \{v\}$;

$V = V - \{v\}$

build temporary set $T = V$;

while $|T| > 0$ **do**

select a node t from T of largest degree;

$T = T - \{t\}$;

If node t has no edge towards any node in S_k **then**

$S_k = S_k + \{t\}$; // join to group k

$V = V - \{t\}$;

end if

end

$k{+}{+}$;

end;

C. Grouping and Bandwidth Allocation Notification

The given grouping scheme modified the superframe structure and the entire active period is partitioned into three parts: contention access period (CAP), group access period (GAP), and contention free period (CFP) as shown in Fig. 3.

It is already described in IEEE 802.15.4 standard that superframe must reserve 22 UBPs for CAP. This minimal period is used by a fresh device to send the management frame for tie up. GAP is partitioned into a number of subperiod by

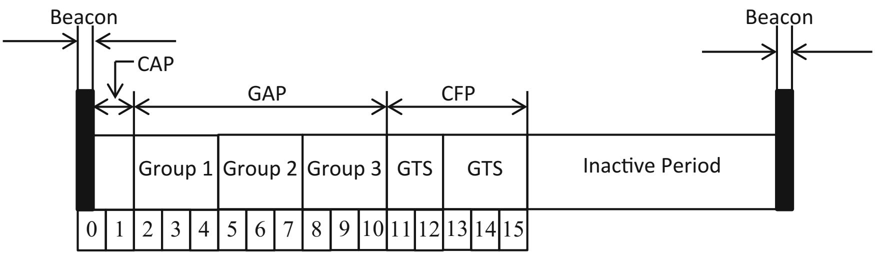


Fig. 3 Modified superframe structure

Octets: 2	1	4/10	2	Variable	Variable	Variable	Variable	2
Frame control	Sequence number	Addressing fields	Superframe Specification	GTS Fields	GIF Field	Pending Address fields	Beacon payload	FCS

Fig. 4 Format of beacon frame

Table 1 Simulation parameters

Parameters	Values
Nodes	1 coordinator, 20 static nodes
BO = SO	3
Frame length	10 & 20 bytes
Transmission range	15 m
Simulation time	300 s
CAP	22 UBPs (=440 symbols)

using slotted CSMA/CA. Note that, if a node wants to send a data and the corresponding subperiod gets expired, it must wait for the next period.

Once the bandwidth is assigned for each group, the GAP result is broadcast by coordinator through beacon frame along with an additional group information field (GIF) as shown in Fig. 4. The GIF field lies between pending address field and GTS field. The optional GIF field have information about group id along with group length. It also contain the information from where GAP slot is started and ends.

4 Experimental Results

In this section, we compare the proposed scheme with IEEE 802.15.4 standard. All the simulation related to experiment is performed on NS3 simulator. In the simulation model, we consider star topology with one coordinator and 20 static nodes. We also assume that medium is free from error and noise. The bandwidth of medium is B bytes/s. Frame arrival rate of every node should precede the Poisson distribution along a mean of λ (frames/s) and L is length of frame. Therefore, traffic load is calculated as $(N \times \lambda \times L)/B$. Table 1 shows the list of parameters that are taken in consideration while performing the simulation.

Figure 5 demonstrates the graph plot between traffic load and goodput (%). Goodput is the total access channel bandwidth measured in percentage. Figure 5a shows the experimental result calculated with respect to frame length of 10 bytes, while Fig. 5b shows the simulation result with respect to frame length of 20 bytes, both of these results are calculated with identical parameters shown in Table 1, except the frame length. These results show that grouping scheme shows the stable

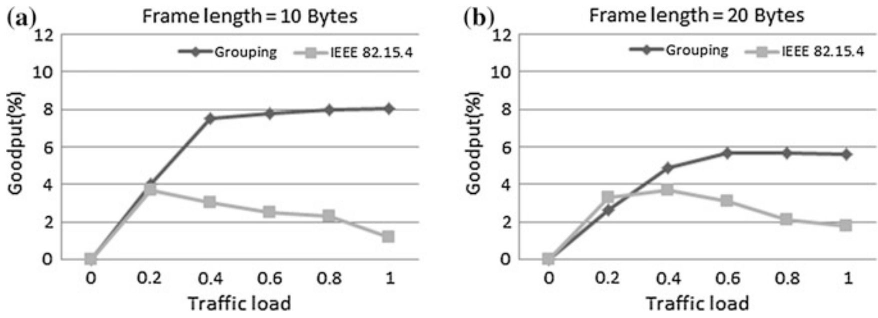


Fig. 5 Goodput versus traffic load **a** goodput when L = 10, **b** goodput when L = 20

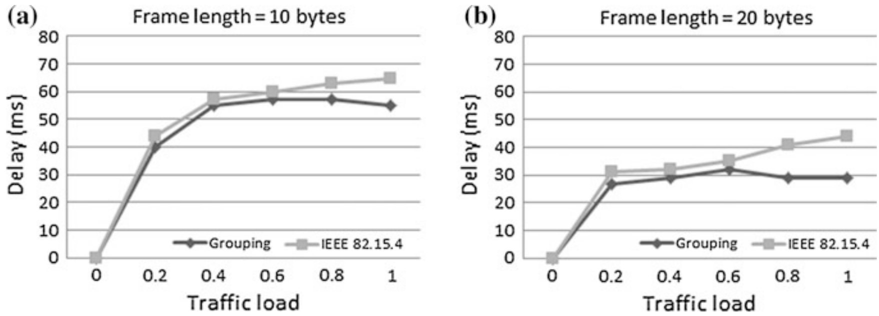


Fig. 6 Delay versus traffic load **a** Delay when L = 10, **b** Delay when L = 20

result in terms of goodput, while IEEE 802.15.4 performance degrades due to the contention.

Figure 6 shows the graph between delay and traffic load, here Fig. 6a shows simulation with respect to frame length of 10 bytes and Fig. 6b with respect to frame length of 20 bytes. These figures show that grouping scheme performed well under heavy traffic load as compared to IEEE 802.15.4. IEEE 802.15.4 performance degrades due to the repeated transmission of collided frame.

5 Conclusion

A simple grouping scheme has been introduced to mitigate the HNC. The given scheme makes use of simple grouping algorithm to construct the groups. The proposed strategy not only enhances the performance of IEEE 802.15.4 devices, but also ensures fare transmission period among them. Simulation outcome shows that given strategy improves the performance in terms of goodput and delay. Finally, we concluded that the proposed strategy enhances the performance of IEEE 802.15.4 protocol along with maintaining the Quality of Service of LR-WPANs.

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