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Partitioned Channel Allocation Scheme for Collision Avoidance in IEEE 802.15.4 LR-WPAN

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Abstract: The IEEE 802.15.4 standard which is widely used in wireless sensor networks, specifies Contention Access Period (CAP) and Contention Free Period (CFP). To access a channel, the IEEE 802.15.4 Medium Access Control (MAC) protocol employs Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) to reduce the probability of collision. However, the probability of collision while gaining access to a channel is high when many active nodes are in CAP, further decreasing its performance. In this study, we propose a partitioned channel allocation scheme. To conduct performance analysis, we used an OPNET network simulator. Our proposed partitioned channel allocation scheme divides the CAP into two sub-periods. To connect to the PAN coordinator, nodes send association request messages to the PAN coordinator. The PAN coordinator then sends an association response message that is present in the Allocation Information of the CAP sub-period (AICAP). Thus, the nodes only use the AICAP to send data and the competition is thereby decreased. Our proposed partitioned channel allocation scheme by adapting the characteristics of IEEE802.15.4 LR-WPAN decreases the transmission delay and energy consumption, it is more efficient than the IEEE 802.15.4 LR-WPAN standard.

Key words: Wireless sensor networks, channel allocation, superframe, IEEE 802.15.4, CSMA/CA, collision

INTRODUCTION

Wireless Sensor Networks (WSNs) (Gutierrez *et al.*, 2011; Buratti, 2010; Jiang and Walrand, 2010) are a technique for the implementation of a ubiquitous computing environment. It is a wireless network environment consisting of many lightweight and low-power sensors. It has been researched and developed to meet various standards by research organizations such as the Institute of Electrical and Electronics Engineers (IEEE) and the Internet Engineering Task Force (IETF). As a result, sensor networks are applied in various fields such as logistics, environmental control and home networks. In addition, the data obtained by sensors in a network are widely used in various fields through data analysis and interaction between services.

IEEE 802.15.4 Low-Rate Wireless Personal Area Networks (LR-WPAN) supports both star and peer-to-peer topologies. In a star topology, a coordinator node is used to establish and maintain a WPAN. In a peer-to-peer topology, a node can communicate with any other nodes within its transmission range. To access a channel, the IEEE 802.15.4 Medium Access Control (MAC) protocol employs Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to reduce the probability of collision (Jiang and Walrand, 2010; Kumar and Ilango, 2015).

However, the probability of collision while gaining access to a channel is high when there is a large number of active nodes in the Contention Access Period (CAP). The result is an increase in the transmission delay and energy consumption.

In this study, we report on our design of a partitioned channel allocation scheme for collision avoidance in the IEEE 802.15.4 LR-WPAN standard. The proposed scheme divides the CAP into two sub-periods. To connect to the PAN coordinator, nodes send association request messages to the PAN coordinator. The PAN coordinator then sends an association response message that is present in the Allocation Information of the CAP sub-period (AICAP). Thus, the nodes only use the AICAP to send data and the competition is thereby

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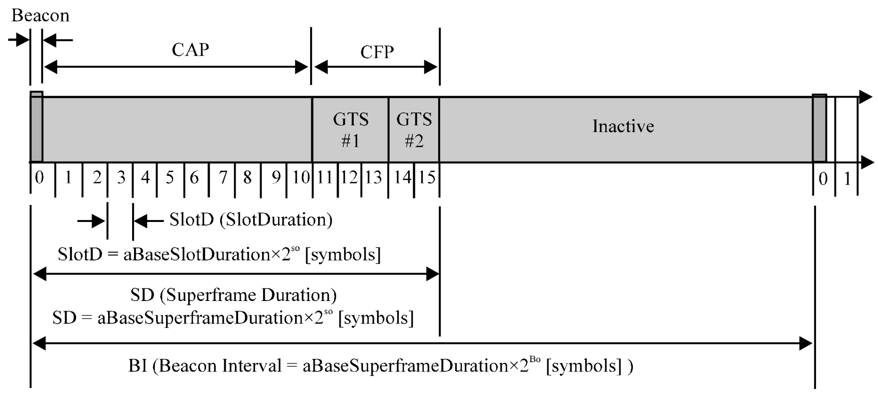

Fig. 1: Example of the superframe structure

decreased. Because the proposed scheme also decreases the transmission delay and energy consumption it is more efficient than the IEEE 802.15.4 standard.

IEEE 802.15.4 MAC: The features of the IEEE 802.15.4 MAC are channel access, beacon management, frame validation, acknowledged frame delivery, association and disassociation. In addition, the IEEE 802.15.4 MAC provides hooks for implementing application-appropriate security mechanisms. The IEEE 802.15.4 standard allows the optional use of a superframe structure. Figure 1 shows the example of the superframe structure (Gutierrez *et al.*, 2011; Cho and Cho, 2010).

The format of the superframe is defined by the coordinator. The superframe is bounded by network beacons sent by the coordinator and is divided into 16 equally sized slots. A superframe is bounded by the transmission of a beacon frame and can have an active portion and an inactive portion. The coordinator may enter a low-power (sleep) mode during the inactive portion (Gutierrez *et al*., 2011; Wang *et al*., 2011; Koubaa *et al.*, 2007).

The structure of this superframe is described by the values of macBeaconOrder and macSuperframeOrder. The MAC PIB attribute macBeaconOrder describes the interval at which the coordinator shall transmit its beacon frames. The BO and BI are related as follows:

$$\text{BI} = \text{aBaseSystemDuration} \times 2^{\text{BO}} [\text{symbols}] \left(0 < \text{BO} \leq 14\right)$$

If BO = 15, the coordinator shall not transmit beacon frames except when requested to do so such as on receipt of a beacon request command. The value of macSuperframeOrder shall be ignored if BO = 15 (Gutierrez *et al.*, 2011; Safdarkhani and Motamedi, 2016; Olempia *et al.*, 2016).

The MAC PIB attribute macSuperframeOrder describes the length of the active portion of the superframe which includes the beacon frame. The value of SO and Superframe Duration (SD) are related as follows:

$$\text{SD} = \text{aBaseSystemDuration} \times 2^{\text{SO}} [\text{symbols}] \left(0 < \text{SO} \leq 14\right)$$

If SO = 15, the superframe shall not remain active after the beacon. If BO = 15, the superframe shall not exist (the value of macSuperframeOrder shall be ignored) and acRxOnWhenIdle shall define whether the receiver is enabled during periods of transceiver inactivity. The active portion of each superframe shall be divided into aNumSuperframeSlots equally spaced slot duration (SlotD):

$$\text{SlotD} = \text{aBaseSystemDuration} \times 2^{\text{SO}} [\text{symbols}]$$

The active portion is composed of three parts: a beacon, a CAP and a CFP. The beacon shall be transmitted without the use of CSMA/CA, at the start of slot 0 and the CAP shall commence immediately following the beacon. The start of slot 0 is defined as the point at which the first symbol of the beacon PPDU is transmitted. The CFP, if present, follows immediately after the CAP and extends to the end of the active portion of the superframe. Any allocated GTSs shall be located within the CFP.

MATERIALS AND METHODS

Proposed partitioned channel allocation scheme: In this study, we present the design of a partitioned channel allocation scheme for collision avoidance in the IEEE 802.15.4 LR-WPAN standard. The proposed scheme divides the CAP into two sub-periods and the nodes accessing the channel are permitted to send data only

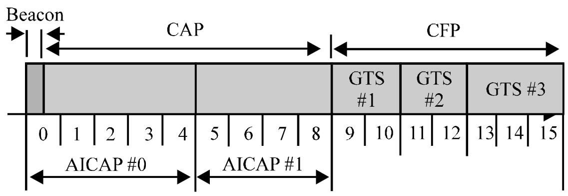

Fig. 2: Proposed superframe structure

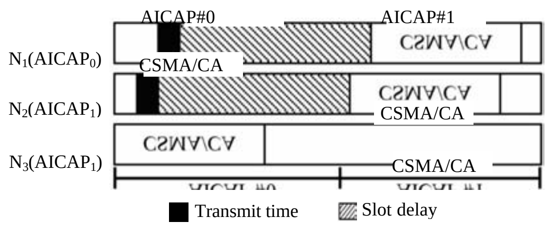

Fig. 3: Slot delay of AICAP #1

within the corresponding AICAP. In this scheme, we assume that the structure of the network is a star topology; association and disassociation of nodes with the PAN coordinator do not occur frequently.

Association scheme: The partitioned channel allocation scheme divides the CAP into two sub-periods. Figure 2 shows this proposed superframe structure.

In order to connect to the PAN coordinator, nodes send an association request message to the PAN coordinator. If the nodes successfully authenticated, the PAN coordinator allocates an association status related to the AICAP to the nodes, that is a status of 0x03 or 0x04 which are additional association status fields of the association response command in the proposed scheme. Table 1 shows the different association status fields of the association response command. Figure 3 shows the allocation of the AICAP algorithm by association.

Channel allocation scheme: Except for acknowledgment frames and any data frame that immediately follows the acknowledgment of a data request command, all frames transmitted in AICAP #0 or AICAP #1 of the CAP use a slotted CSMA/CA mechanism to access a channel. In the proposed scheme, we introduce frame control of the MAC Header (MHR) as shown in Table 2.

To access the AICAP, the value of the frame control is sets to 100 or 101. If the value of the frame control is 100, the node can communicate during AICAP #0. If the value is 101, the node can communicate during AICAP #1.

If aBaseSlotDuration is 60 symbols, the slot duration SlotD is $60\times2^{SO} = 0.96\times2^{SO}$ (msec). If CAP has a SlotD of 8,

Table 1: Association status fields of association response command

Values	Association status
Reserved	0x00
PAN at capacity	0x01
PAN access denied	0x02
Association successful of AICAP#0	0x03
Association successful of AICAP#1	0x04
Reserved	0x05-0x07
Reserved for MAC primitive enumeration values	0x08-0xff

Table 2: Association status fields of association response command

Description	Frame control values
Beacon	000
Data	001
Acknowledgment	010
MAC command	011
Data of AICAP #0	100
Data of AICAP #1	101
Reserved	110-111

the slot start time of AICAP #1 is $\sum^{4}(0.96\times2^{SO})$. Thus, the nodes in AICAP #1 experience slot delay. As shows the slot delay of AICAP #1.

Allocates AICAP algorithm by association

```
//number of joined nodes in AICAP #0
int macAICAP0Cnt = 0
//number of joined nodes in AICAP #1
int macAICAP1Cnt = 0
//number of joined nodes
int joinRequestNodeCnt = 8

For (int i=0;i++;i< joinRequestNodeCnt){
 If (macAICAP0Cnt > macAICAP1Cnt){
    Allocation(AICAP1, NodeAddress[i])
    macAICAP1Cnt++
    SendAssociationResponse(NodeAddress[i]
          Association status(0x04))
 }else{
    Allocation(AICAP0, NodeAddress[i])
    macAICAP0Cnt++
    SendAssociationResponse(NodeAddress[i]
          Association status(0x03))
  }
 }
```

RESULTS AND DISCUSSION

Performance analysis: In this study, we prove that the proposed scheme is more effective than the current standard in terms of transmission delay and energy consumption. Hereafter, we denote the standard as Std and the proposed scheme as PS and compare them.

For performance analysis of PS, we used an OPNET network simulator. We consider a typical WSNs on a surface of size 100×100 m with one PAN coordinator and 16 identical nodes (randomly spread) generated by Poisson-distributed arrivals at an identical arrival rate. Table 3 lists the system parameters for the performance analysis of the proposed algorithm.

Table 3: System parameters

Parameters	Values
macMinBE	3
macMaxBE	5
macMacCSMABackoffs	4
aMaxFrameRetries	3
Packet size (MHR+MSDU)	404 (104+300) bits
ACK frame	11 bytes
Duration time of the simulation	5 sec

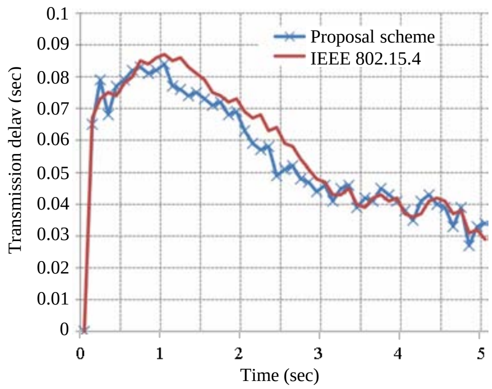

Fig. 4: Comparison of average transmission delay in channel allocation by PS and Std

Channel allocation scheme: In this subsection, we prove that PS is more effective than Std in terms of transmission delay. Figure 4 shows a comparison on the average transmission delay in the channel allocation by PS and Std.

As shown in Fig. 4, during the period from 0-1sec, the transmission delay rapidly increases because of the high number of nodes that are sending packets to the PAN coordinator and after 1.3 sec, the transmission delay begins to decrease slowly. Table 4 lists the average transmission delay in channel allocation of PS and Std.

The results show that the average transmission delay in channel allocation by Std is 0.568 sec. On the other hand, the average transmission delay in channel allocation by PS is 0.559 sec. Thus, the transmission delay by PS is approximately 1.59% < that by Std.

Energy consumption: In this study, we prove that PS is more effective than Std in terms of energy consumption. Figure 5 shows a comparison of the average energy consumption by PS and Std for channel allocation.

As shown in the Fig. 5, during the period from 0-1sec, the energy consumption rapidly increases because of the high number of nodes that are sending packets to the PAN coordinator. After 1.3 sec, the energy consumption begins to decrease slowly. Table 5 lists the average energy consumption for channel allocation of the two schemes.

Table 4: Average transmission delay in channel allocation by PS and Std

Time (sec)	0-1	1-2	2-3	3-4	4-5	Avg.
PS	0.780	0.718	0.511	0.421	0.364	0.559
Std	0.789	0.759	0.555	0.408	0.328	0.568

Table 5: Average energy consumption for channel location by PS and Std

Time (sec)	0-1	1-2	2-3	3-4	4-5	Avg.
PS	0.000651	0.000589	0.000388	0.000291	0.000233	0.000430
Std	0.000654	0.000618	0.000418	0.000280	0.000210	0.000436

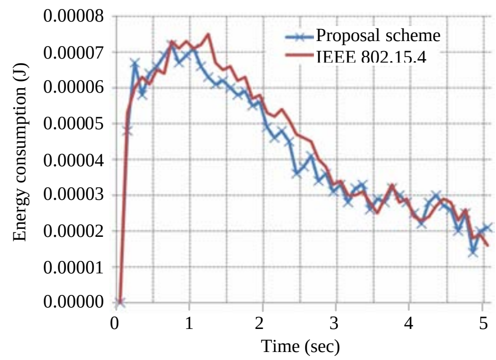

Fig. 5: Comparison of average energy consumption for channel allocation by PS and Std

The results show that the average energy consumption for channel allocation by Std is 0.000436 J. On the other hand, the average energy consumption for channel allocation by PS is 0.000430 J. Thus, the energy consumption by PS is approximately 1.28%< that by Std.

CONCLUSION

The IEEE 802.15.4 standard which is widely used in WSNs, specifies CAP and CFP. To access a channel, the IEEE 802.15.4 MAC protocol employs CSMA/CA to reduce the probability of collision. However, the probability of collision while gaining access to a channel is high when there is a large number of active nodes in CAP. The result is a degraded performance.

In this study, we propose a partitioned channel allocation scheme for collision avoidance in IEEE 802.15.4 LR-WPAN. The proposed scheme divides CAP into two sub-periods. The nodes use only the AICAP for sending data and the competition is decreased.

In order to evaluate the performance of the proposed scheme, we showed that it is more effective than the IEEE 802.15.4 standard in terms of transmission delay and energy consumption.

RECOMMENDATIONS

As a further step, the equipment required for the scheme's practical deployment needs to be specified and its performance under such conditions needs to be evaluated.

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