IEEE 802.15.4기반의 제어용 무선 네트워크에 대한 연구

Wireless Networked Control Systems Using IEEE 802.15.4

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요 약

In this paper, a wireless control network based on IEEE 802.15.4 MAC protocol is proposed. The superframe of IEEE 802.15.4 is applied to the proposed wireless control network. The transmission and bandwidth management method are proposed for efficient transmission in the superframe. By these methods, the proposed wireless control network protocol is able to transmit three types of data (periodic data, sporadic data, and non real-time message), and guarantee real-time transmission within deadline.

Key Words : Wireless control network, IEEE 802.15.4, Real-time transmission

1. INTRODUCTION

The general industrial environment is composed of a number of sensors, actuators and I/Os. They exchange their data with a master station by peer-to-peer. Most transmitted I/O data are lower than 1 byte except a network maintenance data [1]. The Fieldbus should be able to transmit a real-time periodic data, sporadic data for alarm and non-real-time message data for network maintenance [2]. By these limitations, most existing Fieldbuses are based on wired technology.

There have been some studies on the wireless control network technology using IEEE 802.11 [3]-[6]. A hybrid Fieldbus technology based on Profibus was presented for wireless extension [3] [4]. In [5] [6], the wireless control network based on IEEE 802.11 was described, it is called R-fieldbus. However, IEEE 802.11 node has high cost and reliability limitation. In general, many nodes should be allocated in industrial environment. Therefore, the wireless control network based on IEEE 802.11 has problems because of high installing and maintenance cost. The wireless control network based on Bluetooth technology was proposed [7]. Bluetooth has low cost and fast transmission rate, but it should be composed of few node and has short range. Hence, it is difficult to apply in wide factory area with a number of node.

In this paper, the efficient transmission method of mixed traffic(real-time periodic, real-time sporadic, non real-time message) is proposed using a superframe of IEEE 802.15.4. To the best knowledge of the authors, the wireless control network based on IEEE 802.15.4 has not been reported on yet in the technical literature.

2. WIRELESS CONTROL NETWORK BASED ON IEEE 802.15.4

2.1 Superframe of IEEE 802.15.4

In order to transmit real-time traffic effectively, the superframe structure of IEEE 802.15.4 has to be modified. Fig. 1 shows the modified superframe structure. The real-time periodic data is transmitted in the CFP and re al-time sporadic data and non real-time message can be transmitted using CAP. The inactive period is defined to zero to reduce delay.

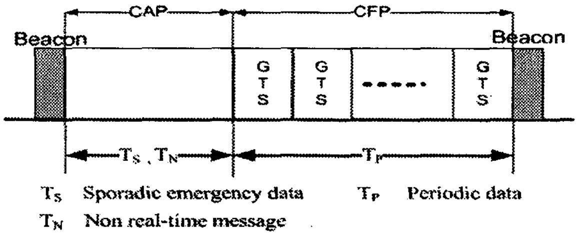

Fig. 1 Frame structure of modified superframe

The real-time performance depends on a length of the basic period. The basic period is used to schedule periodic node and determine transmission period of periodic data. In this paper, the length of a superframe is used as the basic period. Therefore, the length of a superframe is minimized to reduce transmission period. The length of a superframe is determined by Equation (1).

$$T_{SF} = T_{BD} \times 2^{SO}, \quad (1)$$
$$T_{BD} = 480Byte,$$
$$0 \le SO \le 15$$

where, the T_{SF} is the length of a superframe. The T_{BD} represents the base superfrmae duration that is a constant of a mac sublayer. The SO stands for the superframe order and can be set at MAC PIB. The transmission rate of IEEE 802.15.4 is 250kbps. Hence, if SO is defined to zero, the duration of superframe is 15.36ms. If some data need transmission period lower than 15.36ms, it can not be transmitted.

The seven slots, which are maximum number of allocated slot to CFP, are allocated to the CFP because most of data in industrial environment is periodic data. A length of GTS can be written as Equation (2).

$$T_{slot} = T_{Bslot} \times 2^{SO}, \quad (2)$$
$$T_{Bslot} = 30Byte$$

where, the T_{slot} and T_{Bslot} represent one slot duration and the base slot duration, respectively. T_{Bslot} is a constant of a mac sublayer. If the SO is zero, the length of one slot can be calculated as 0.96ms. The coordinator should determine the number of allocated GTS of nodes by the length of data and the IFS. If the data frame format of IEEE 802.15.4. is used and transmitted as no-acknowledge mode, the number of allocated GTS can be calculated as the following equation (3).

$$T_{NGT} = \left\lceil \frac{T_O + T_d + IFS}{T_{slot}} \right\rceil \quad (3)$$
$$IFS = \begin{cases} T_d \le 5Byte, & IFS = SIFS = 6Byte, \\ T_d > 5Byte, & IFS = LIFS = 20Byte \end{cases}$$

where, $\lceil Z \rceil$ is the smallest integer larger than or equal to the value Z. T_{NGT} represent the number of allocated slot. T_O is the length of remainder frame except for payload in data frame format of IEEE 802.15.4. T_d is the length of transmitting data. In the case of 2 byte address mode, T_O can be used as 19 bytes. If the length of data is less than 5 bytes, the number of allocated GTS is calculated as 1. In industrial environment, the length of most periodic data is less than 4 Byte. Hence, most of periodic data can be transmitted within 1 GTS.

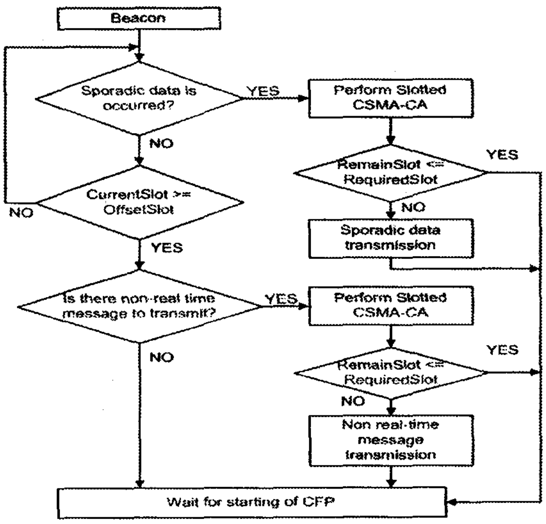

Fig. 2 Flow chart of procedure on CAP

The CAP occupies more than half of the superframe. Therefore, it is necessary to menage bandwidth of CAP to improve real-time performance. In CAP, the realtime sporadic data and non real-time message data can be transmitted.

In Fig. 2 the flow chart of bandwidth management in CAP is described. The CAP is started after beacon frame, then the sporadic nodes try to access to channel immediately. The sporadic node succeeding in channel access compares the number of required slots to transmit with remaining slots in CAP. If number of remaining slots is larger than requ ired slots, the node starts transmission. This case is described in the case 1 of Fig. 3.

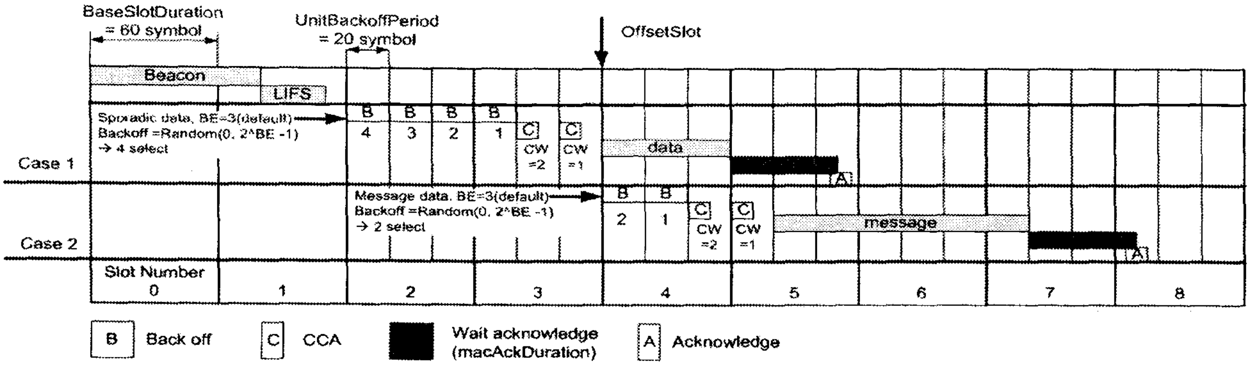

Fig. 3 Timing chart of CAP

The non real-time message node try to access to channel after the OffsetSlot as shown the case 2 of Fig. 3. The OffsetSlot is used to give a priority of channel access to the sporadic node. If the coordinator wants to transmit non real-time message, there should be no sporadic node access to channel begin the OffsetSlot.

2.2 Network Maintenance

In this paper, the modified GTS request frame is used for maintenance of periodic nodes that the 1 byte deadline field is added to the GTS request frame. The deadline field contains a deadline of periodic data. The coordinator has the scheduling table contains the addresses and deadlines of periodic nodes. By this scheduling table, the coordinator schedules periodic nodes and allocates GTSs.

For scheduling, the multiple of the superframe duration is determined to the transmission period of each node. By the deadline of each node, the transmission period of the ith real-time periodic data is calculated by Equation (4).

$$T^i_{TP} = \left\lfloor \frac{T^{i_D}}{T_{SF}} \right\rfloor \times 16, \qquad (4)$$

where, $\lfloor Z \rfloor$ is the largest integer smaller than or equal to the value Z. T^i_{TP} represents ith transmission period. T^i_D is the deadline of ith node. The number of GTS, the ith real-time periodic node can use within its transmission period, can be written as

$$T^i_{UGT} = \frac{T_{TP}}{16} \times 7 \qquad (5)$$

where, T^i_{UGT} is the usable GTS of ith node. By the number of the usable GTS of each node, the GTS allocability can be checked on following Equation (6).

$$U_{GTS} = \sum_{i=1}^{n} \frac{1}{T^i_{UGT}} \le 1, \qquad (6)$$

where, U_{GTS} represents the GTS utilization. If Equation (6) is not satisfied, the GTS can not be allocated.

In the case of a new periodic nodes inserted to network, the procedure is described as following :

1. A inserted periodic node transmits the modified GTS request frame to coordinator.
2. The coordinator receives modified GTS request frame determines the transmission period by Equation (4) and checks a GTS allocability by Equation (6).
3. If the GTS can be allocable, the coordinator includes the new node to schedule table and then starts GTS allocation by new schedule table.
4. Equation (6) is not satisfied, the coordinator rejects a GTS request of periodic node.

The periodic nodes are scheduled by the earliest deadline first algorithm (EDF). Before the beacon frame broadcasting, the coordinator reschedules the periodic nodes by EDF algorithm and allocates GTSs to periodic nodes by scheduling result. After the periodic nodes transmit data at allocated GTS, remove their information of allocated GTS to take new GTS information in next superframe.

3. SIMULATION

For a simulation, the following assumption s are used ;

- In the CFP, the real-time periodic data i s transmitted by the data frame format and the no-acknowledge mode is used.

Table 1. Deadline, transmission period, and usable GTS of each periodic node

Node No.	$T_D(ms)$	$T_{TP}(slot)$	$T_{UGT}(slot)$
1 ~ 3	20	16	7
4 ~ 8	50	48	21
9 ~ 10	100	96	42

- The length of real-time periodic data is lower than 5 Byte. These assumptions are u sed to allocate one GTS to a periodic node.

For the simulation, the network is configured with ten nodes for real-time periodic data on Table 1. the T_D, T_{TP}, and T_{UGT} of each no de is described. The T_{TP}, and T_{UGT} can be obtained by Equation (3) and (4), respectivel y. By Equation (5), the U_{GTS} can be obtaine d as

$$U_{GTS} = (\frac{1}{7}\times 3)+(\frac{1}{21}\times 5) + (\frac{1}{42}\times 2) \simeq 0.71 \ . \quad (7)$$

Hence, the GTSs can be allocated to peri odic nodes. In Fig. 4, the result of GTS allo cation is shown. Fig. 4 shows the consecutiv e six superframes. The node numbers at a CFP are shown at Table 1. The empty GTS s are allocated to the network maintenance b y the coordinator.

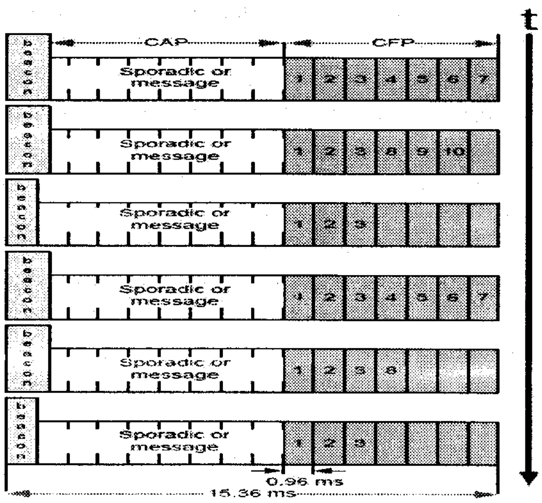

Fig. 4 GTS allocation result

4. CONCLUSION

The proposed wireless control network pro vides a reliable data transmission using the superframe of IEEE 802.15.4 MAC protocol. The periodic data is transmitted using GTS in CFP. Separating CAP properly, the sporad ic and non real-time message are transmitte d effectively. The designed wireless control network can guarantee to transmit the real-t ime periodic and sporadic data within dead li nes around 100ms.

As a future direction of this work, one ma y be consider a beacon scheduling for multi coordinators and dynamic GTS scheduling a nd allocation algorithm.

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