A Slotted CSMA/CA of IEEE 802.15.4 Wireless Sensor Networks: A Priority Approach

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Abstract: *The heterogeneous traffic categorization is the critical challenge in wireless sensor networks. Therefore, this paper presents the beacon enabled-slotted CSMA/CA with priority approach for delivering the significant data first over the regular traffic. The priority metric is designed to assign the weight factor dynamically for delivering the required data packets at the earliest. It includes delay and priority information for computation of node priority weight and evaluated over the star topology. It is observed that it shows 6% improved performance from the prioritized data frame transmission perspective. The presented work is simulated in ns2 and examined over the various scenarios to validate the performance of the priority approach using CSMA/CA IEEE 802.15.4 wireless sensor networks.*

Keywords—*wireless sensor networks, priority, slotted CSMA/CA, IEEE 802.15.4, delay sensitive*

I. Introduction

The emergency or critical applications have gained the attention of more active researchers in the field of low rate wireless sensor networks [1]. Nowadays the wireless sensor network is being used for various purposes where the data rate requirement is low, particularly in the medical field, industrial automation, residential projects, and tracking systems and much more [2]. To address such variety of applications, the IEEE 802.15.4 standard has developed CSMA/CA MAC and PHY layer especially for 250kbps data rate requirement applications [3]. The MAC presents two protocols, namely, beacon enabled slotted-CSMA/CA protocol and beaconless CSMA/CA protocol. For the delay sensitive applications, delivering the data in time is a non-trivial task. Such time bounded applications; a slotted CSMA/CA with GTSs (Guaranteed Time Slot) allocation plays a significant job to reduce the delay. Therefore, the scope of the paper focuses on slotted CSMA/CA mechanisms to achieve the reliable data delivery of sensitive traffic generating nodes. The slotted CSMA/CA gives the guarantee of the highest level of data delivery by allocating dedicated slots for such critical traffic originating nodes. However, there is various existing beacon enabled MAC layer protocols have been developed such as S-MAC [4], T-MAC [5] and Wise-MAC [6]. However, non-beacon enabled X-MAC [1-11] and B-MAC [7] uses the asynchronous type of communication. A beacon enabled network uses the synchronous type of communication for effective use of duty cycle mechanism. This is useful for better power utilization [8]-[11].

The purpose of choosing the beacon enabled mode is to save the energy efficiently for low rate data transmission. The Sensor-MAC follows the periodic duty cycle to synchronize the active nodes. It uses the RTC/CTC mechanism to minimize the burden and reduce the congestion level. The timeout-MAC offers the dynamic duty cycle approach to reduce the listening time of traffic into the network. Nevertheless, the fixed duty cycle mechanism suffers from the high delay experience but due to dynamism in duty cycle control operations, it automatically switches from active to passive state when there is no load in the network.

II. Related Work

This section presents the existing reference work related to slotted-CSMA/CA protocols for the low rate IEEE 802.15.4 sensor networks. In [12], the delay analysis model is presented using CAP and CFP period effectively over the multi-hop and star topology. The model is designed to develop the MAC parameters to select the appropriate topology. The precedence control scheme [13] is designed and developed for prioritizing the information over the multi-hop topology. The cluster topology based Multichannel Superframe Scheduling (MSS) approach of the beacon interval (BI) and superframe distribution (SD) is presented in [14] for an industrial wireless sensor network (IWSN). It comprises cluster division; first-time slice based scheduling, time slice boundary computation, and programming in cluster st_2.

The flow balanced scheduling using GTS TDMA mechanism designed to address the problem of rate differentiation for the class of traffics in [15]. The variable transmission rate is configured based on the time bound and event criticalness. The weighted tree is designed and specific interval allocation is presented for relay nodes. The metric is presented to compute the number of SD requirements to each node. In [16], DRX and FDRX methods are proposed to address the delay sensitive applications. While handling the fairness index is also taken into account in the FDRX method. It operates with basic MAC operations. The FDRX method does not allow all the time to dominate nodes to gain the channel access. Furthermore, if any node is found that its delay is being exceeded then such nodes are handled at priority level by checking the threshold value. The comparative performance analysis [18] describes the QoS parameter performance insights. The [17] protocol shows the priority approach for reliable data transmission.

III. A SLOTTED CSMA/CA PRIORITY APPROACH

The proposed approach delivers data packets reliably over the multi-hop network. The objective is to deliver the long distance traffic first. The superframe consists of three parts, namely CAP, CFP, and an inactive period. The superframe starts with a beacon signal and immediately CAP period activates for source nodes to send their data packets. The nodes contend for media access and whoever gets the channel by performing two times CCA symbols by PHY layer then such node is allowed to deliver their sensed traffic first.

In this protocol, it is assumed that the nodes who deliver the data in CAP window are having less priority weight as compared to other nodes. As soon as its window time expires the CFP period starts. Here, nodes with high priority weight do not have to contend for the channel access. They are already defined with slot by the base station. According to their slot, they need to send the data into this time frame window. The slot is called as guaranteed time slot (GTS). After completion of CFP period of one superframe structure, all nodes immediately switches in sleep mode as inactive period starts. There are total 16 slots out of 7 slots are used for the CFP and 9 slots are used CAP window. The total duration is 960 symbols (one symbol=4bits) is defined by the IEEE 802.15.4 standard (which indicates 15.36ms in the case of 250kbps, 2GHz band) [19]. The length of the superframe is defined in equation (1).

$$SD = aBaseSD \times 2^{macSO}$$

For

$$0 \leq macSO \leq macBO \leq 14. \qquad (1)$$

The mathematical term description is shown in table 1.

Table 1
Mathematical term description

Term	Definition
p_{wt}	Priority weight (initial-1,0)
d	delay(seconds)
α	Tuning parameter (0.03)
macSO	macsuperframeOrder
macBO	macsuperframeBeaconOrder
aBaseS	aBaseSuperframeDuration
h_c	hop count

The priority first approach of slotted CSMA/CA presents the data frame transmission based on the priority information of each contributing node. The star topology is used for proposed protocol implementation for low rate IEEE 802.15.4 networks, as shown in figure 1.

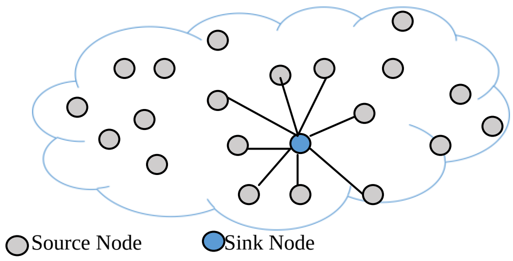

Fig.1. Star topology view of Prioritized slotted CSMA/CA for IEEE 802.15.4 networks

In the initialization phase, every node provides the information to the sink node in order to compute the priority weight. The sink node checks the priority bit and network delay. Whichever node reports the more delay gets the highest priority into the network. The metric calculates the priority weight to each active node of the network. The priority weight is computed as expressed in equation 2.

$$P_{wt}(s_i) = p_{wt} + h_c d^{\alpha} \qquad (2)$$

The sink node assigns the 7 GTS slots (Guaranteed Time Slots) to those nodes whose priority weights are higher among the all reported nodes to the sink node. These slots are sequential as per time frame of CFP window. The first time slot gets assigned to the highest priority weight node; next slot gained the access by the next high priority weight node and so on till seven slots are over. However, the nodes those who do not get the time slot of CFP window they automatically go into CAP window for contending the channel access. The sink initially broadcasts the beacon signal to all one hop source nodes.

Afterward, the nodes who do not receive the time slot they try to gain the channel access when CAP time frame is commenced. Here, total 9 slots are available to all source nodes that have already reported to the sink node and are synchronized with it. Every node fights for channel according to their backoff timer. For example, the backoff period of a particular node is expired then it immediately performs the two-time CCA (Clear Channel Assessment) method by PHY layer with default option in order to gain the channel access for actual data frame transmission. Once it finds channel immediately take a hold and start transmitting the data frames.

The CFP window is commenced just after the CAP window. In particular, each slot is dedicatedly assigned to each node prior and to this activation their backoff windows have synchronised the start of time slots. In seven slots seven nodes are allowed to deliver the data packets. After expiry of CFP window, the inactive frame window gets activated and all source nodes go to the sleep state for a while. The purpose is to clear all control overheads in order to avoid the collisions in subsequent superframe.

Algorithm 1: A Priority First Approach for Slotted CSMA/CA

Input: s_i
Output: priority-based data transmission
Prerequisites: Star topology formation, Priority Assignment
Slot allocation phase
Begin

1. Send_beacon (s_i);
2. S←join(s_i);
3. Compute_priority(info);
4. $\boldsymbol{if}$ ($s_i \in s_p$) do
5. $s_p \leftarrow \boldsymbol{GTS\ slot}$; //CFP window slots
6. $\boldsymbol{else}$
7. s_{np} contends for media access
8. Broadcast(t_n);
9. Transmit(d_f);

END

The step by step operational flow is described in algorithm 1.

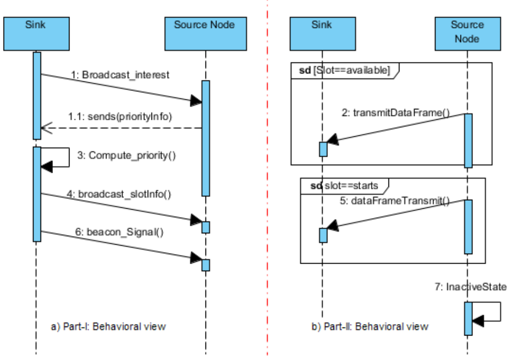

Fig. 2: The packet delivery ratio comparison

The sink node sends the beacon signal to all source nodes that are in the radio range. Every node has to report their priority type information and network delay. The priority metric is used to those source nodes that have declared as delay sensitive information nodes. Therefore, based on the network delay and priority bit (i.e. 1) are used for computation of their weight so that they will get an earlier chance even among the number of high priority nodes in the particular region. Furthermore, GTS slots are assigned to first seven nodes when the first beacon is transmitted to all nodes. This process continues until complete transmission of data frames of active nodes. The behavioural view of the proposed priority approach is depicted in figure 2.

IV. PERFORMANCE ANALYSIS

The priority-based approach is simulated in ns2 discrete event simulator. The results are validated by performing various scenarios with different simulation time in order to prove the correctness of the results. Therefore, the reported work in the article is the average of five experiments in the same setup.

Table 2
Network Simulation Setup

Attributes	Values
Sensing field area	500x500m^2
No. of source nodes	101
Simulation Time (sec)	75,100,125,150,175,200
Transmission range	30m
IF Queue Length	50
Packet size	30byte
Transmit Power	0.660w
Receive power	0.395w
Initial Energy	100J

The illustration of the priority metric is described in table 2 according to equation (2). The metric is used for the assignment of the node priority. This study focuses only the node level priority instead of data packet priority. The initial bit of high priority is 1 whereas low priority denotes 0. However table 2 shows the generic illustration over multi-hop topology but as far as star topology is considered then only one would be taken into the consideration.

Table 2
Illustration of priority weight

High Priority	Low Priority
$p_{wt} = 1 + 5 * 0.013^{0.03} = 5.389$	$p_{wt} = 0 + 5 * 0.013^{0.03} = 4.389$
$p_{wt} = 5.389 + 4 * 0.017^{0.03} = 8.929$	$p_{wt} = 4.389 + 4 * 0.017^{0.03} = 7.929$
$p_{wt} = 8.929 + 3 * 0.021^{0.03} = 11.6$	$p_{wt} = 7.929 + 3 * 0.021^{0.03} = 10.6$
$p_{wt} = 11.6 + 2 * 0.025^{0.03} = 13.39$	$p_{wt} = 11.6 + 2 * 0.025^{0.03} = 12.39$
$p_{wt} = 13.39 + 1 * 0.028^{0.03} = 14.289$	$p_{wt} = 12.39 + 1 * 0.028^{0.03} = 13.289$

The network performance parameters, namely packet delivery ratio, delay, throughput, jitter, and energy consumption is presented in this paper. The analysis depicts the results of priority nodes over no-priority performance perspective instead of overall.

1) Packet Delivery Ratio (PDR)

Fig. 3 shows 6% to 8% variation in terms of packet delivery ratio of the priority-based CSMA/CA protocol against the standard CSMA/CA protocol. Furthermore, the priority based protocol illustrates the PDR approximately 86% whereas CSMA/CA shows approximately 81%. The packet loss ratio has been decreased due to consideration of delay and priority factor while delivering the delay sensitive data first into a star based sensor topology.

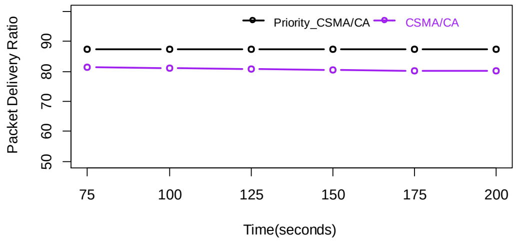

Fig 3: The packet delivery ratio comparison

2) *Delay study*

Fig.4 illustrates the comparison in-between the priority based approach against the traditional communication mechanism of CSMA/CA protocol. The 3% to 7% variation is noted with the standard protocol. This significant improvement is achieved due to prioritization of delivery of different traffics by the different source nodes.

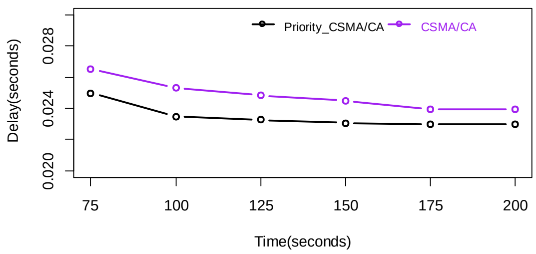

Fig 4: The delay comparison over different times

3) *Jitter Analysis*

Fig. 5 shows the variation in delay i.e. jitter analysis. The 6% to 8% change is observed during experimentation at different times. The presented each point in the graph is the average of five experimentations over the same setup. Though it is reasonable small but from delay sensitive application point of view, this is also measurable. Hence, shows improvement in reduction in delay as well.

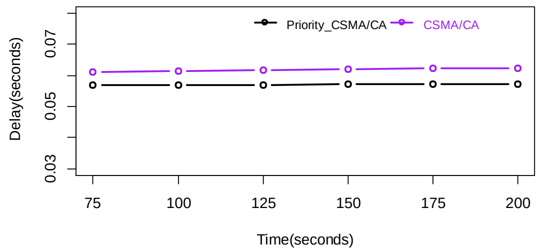

Fig 5: The jitter comparison over varied times

4) *Goodput Comparison*

Fig. 6 explains the actual data frame performance over the standard protocol for sensor networks.

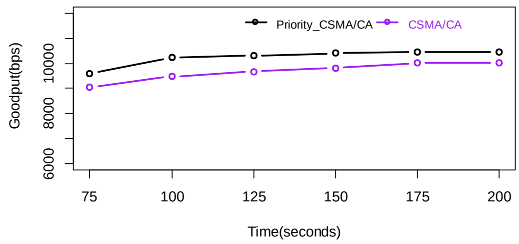

Fig 6: The Goodput comparison over varied times

The 6% average performance is noted down against the standard protocol. It proves that the priority metric increases the delivery ratio to the greater extent and due to that the performance of the network is improved significantly.

5) *Average Overheads per Nodes*

Fig. 7 describes the number of control packets taken for setting up the proposed approach. The simulation time is indirectly proportional to the number of overheads per node. On an average, both protocols require the approximately 3 control packets.

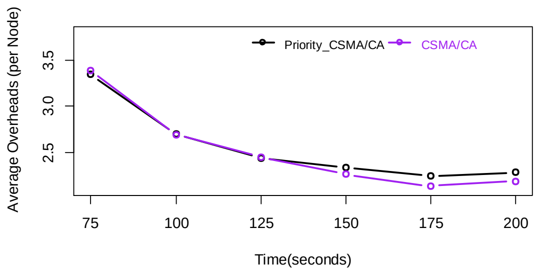

Fig 7: The jitter comparison over varied times

6) *Energy Consumption Evaluation*

Fig.8 illustrates the energy consumption 23% average improvement with the traditional CSMA/CA protocol for specific priority approach perspective for the said topology.

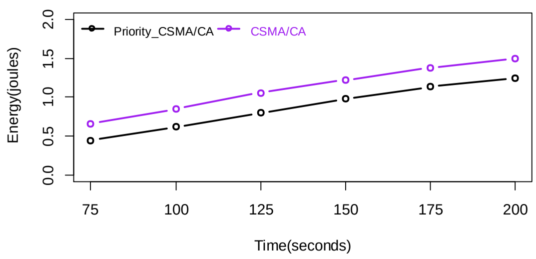

Fig 8: The jitter comparison over varied times

Furthermore, it gives the first preference to priority node instead no-priority nodes. This is the significant improvement has been noted.

V. Concluding Remarks

This paper presents the performance analysis of priority-based CSMA/CA protocol over the traditional CSMA/CA. The network performance parameters such as goodput, packet delivery ration, network delay, overheads, and energy consumption are examined. The priority approach shows around 6% improved performance over the traditional protocol. The delay and priority information are used for node prioritization which plays a non-trivial job for delivering the data frames in time. However, it is also observed that the long distance traffic get the channel access earlier over short distance traffic. Thus the packet delivery ratio is improved approximately 6%. This reported work would be useful for delay sensitive sensor application.

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