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Performance Analysis of Beacon enabled Prioritized CSMA/CA for IEEE Sensor Networks

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Abstract

The delay sensitive application experiences the problem of meeting the deadline without collision in the low rate wireless sensor network. In sensor networks, every application does not require high packet delivery ratio or high throughput rather it demands the accuracy in delivering the small amount of data. Thus this paper presents the priority-based approach for delay sensitive applications over the delay tolerant applications in the heterogeneous wireless sensor networks. The slotted standard CSMA/CA beacon enabled MAC protocol does not address the prioritization of information but guarantees the delivery of data collision-free; therefore, the slotted protocol considered and modified from the priority perspective. The priority type, namely high and no is assigned to every source node and based on this information the base station allocates the GTS slot in CFP window whereas other nodes contend for the channel access randomly according to their backoff timer CAP window. This approach improves the data delivery faster in the multi-hop network topology. The presented work is simulated in ns2 and examined using various scenarios over different simulation times. The analysis shows that slotted CSMA/CA with priority approach takes less delay and produces significant goodput.

Keywords: Priority; slotted CSMA/CA protocol; beacon enabled wireless sensor networks; IEEE 802.15.4 sensor networks; reliable data communication

INTRODUCTION

The IEEE 802.15.4 sensor network is an emerging wireless technology for small data rate applications. The recent advancements have created sufficient impact over the various electronics appliances, namely fridge, washing machine, home lighting, water purifiers, and much more where the data transmission range and volume are less as compared with traditional systems. It not only focuses on door applications but it is being used in object tracking remotely, controlling home through the internet, military surveillance, monitoring, traffic management, emergency event reporting wirelessly, gardening, energy monitoring [1,2], biomedical sensor networks particularly for health[3], and many more sectors. Due to its long life, it is one of the important key factors for choosing such remote and long life devices [4]. It uses AA batteries that give life to the devices which last approximately up to 10 years. Therefore, nowadays it is one of superior wireless technology for such light weight applications. It has been extended and used for smart city development; recently because of having the range extending capability in available hardware, especially supported by the mesh topology.

Besides, the devices which are available in the sector are having the capacity of self-joining, self-healing, self-configurable, and self-adjustable reporting rate. These distinctive features differentiate it from the other wireless technologies; making it most efficient solution for the little processing, low memory, and low range applications. However, developing the solution for delay sensitive applications is the non-trivial task particularly of considering processing overheads. The IEEE 802.15.4 standard [12] has defined two MAC protocols mainly beacon enabled CSMA/CA and beaconless CSMA/CA protocols. However, selecting the appropriate one is the choice of concerns from the application requirement perspective. In both the modes of operation, there is one common problem i.e. handling the delay sensitive data delivery before expiry [5-7], otherwise delivering the data even becomes useless if it reports late. The contention based protocols like S-MAC [8], T-MAC [9], B-MAC [10], X-MAC [11], are studied to address the problem efficiency in data delivery, however still suffers from the collision, traffic load, and topology variations. Mainly, the LR-WSN comprises the event driven and continuous data reporting types of applications. In these two modes of operations, reducing the transmission overheads is the directly proportional to power saving. Therefore, in the single hop or multi-hop topology; handling the data at various points becomes the necessity to reduce the network latency and improve the data reliability of different events which occur simultaneously.

The slotted CSMA/CA protocol of the IEEE 802.15.4 provides the collision-free data frame delivery; getting higher throughput through data delivery mechanism is not always the better solution; rather handling the sensitive information of a particular node is also an important aspect of the emergency situation. In the most of the existing protocols, the prime focus is given for achieving maximum packet delivery though it is important to address still handling the delay sensitive information first over the heterogeneous wireless sensor network is an also critical parameter to reduce the latency of those applications. Considering these issues, we aim to focus on the priority-based data delivery to the desired location using the superframe structure of the IEEE 802.15.4 [12].

In [13], the priority-based delay mitigation scheme proposed for the event driven low rate wireless sensor networks. It comprises two sub-methods, namely, frame tailoring and priority toning. The analysis describes that it gives the guarantee of precedence delivery within a time bound. It is validated by varying the workload and verified the packet delay at every setup. The ER-MAC [14] proposes the time to switch mode from regular monitoring to emergency reporting state in response to events. It supports to heavy traffic, changes on topology, and packet classification and fairness support. It uses TDMA to make collision-free data frame transmission. For the emergency events, the packet transmission is increased almost four times over the Z-MAC protocol. In [15], the hybrid approach i.e. CSMA/TDMA is proposed to overcome the high energy consumption and throughput in heavy traffic load. It provides the TDMA slot allocation concerning the frame and computes the number of slots utilized, number slots unused and some slots has found collided. The priority based approach is useful for heterogeneous data flows in LR-WSNs [16, 17].

This paper focuses on the slotted CSMA/CA with priority-based data transmission for delay sensitive applications. The node with priority is defined a dedicated slot and allowed to deliver their data without signal collision and any waiting time for accessing the channel. Therefore, such provision makes faster and serves in time without any mishap happens due to delay. Therefore, priority approach brings significant data delivery allowance for high traffic flows over regular monitoring flows in the network. For this reason, the standard CSMA/CA protocol modified for making application specific requirement perspective without diverting its unique features of low rate wireless sensor networks.

The remaining sections of this paper are organized as follows. Section 2 describes the priority-based approach using beacon enabled CSMA/CA for delay sensitive applications. The performance analysis is presented in section 3. Finally, the reported work concluded with future directions in Section 4.

PRIORITIZED CSMA/CA APPROACH

A. Network Model & Assumptions

The multi-hop topology is formed for assessing the standard CSMA/CA protocol. The definitions of mathematical terms are described in Table 1.

Table 1: Description of Mathematical terms

Term	Definition
n	source nodes
n_{np}	no-priority nodes
n_p	priority node
T_{bkoff}	backoff timer
t_{slot}	time slot
t_{cca}	time required to perform clear channel assessment
t_{gts}	guaranteed time slot
$t_{inactiveSlots}$	inactive time slot

The sink node initiates the communication for node synchronization and slot assignment before actual data frame transmission starts as shown in figure 1. The priority is assigned based on the node priority level information. The sink node allocates the slot on the FCFS basis for the priority nodes whereas for other nodes allow for accessing the media in the CAP window as described in figure 2. If they sense the channel free then immediately starts forwarding the actual data frames; otherwise, resets the backoff timer and waits to become its timer zero to perform again.

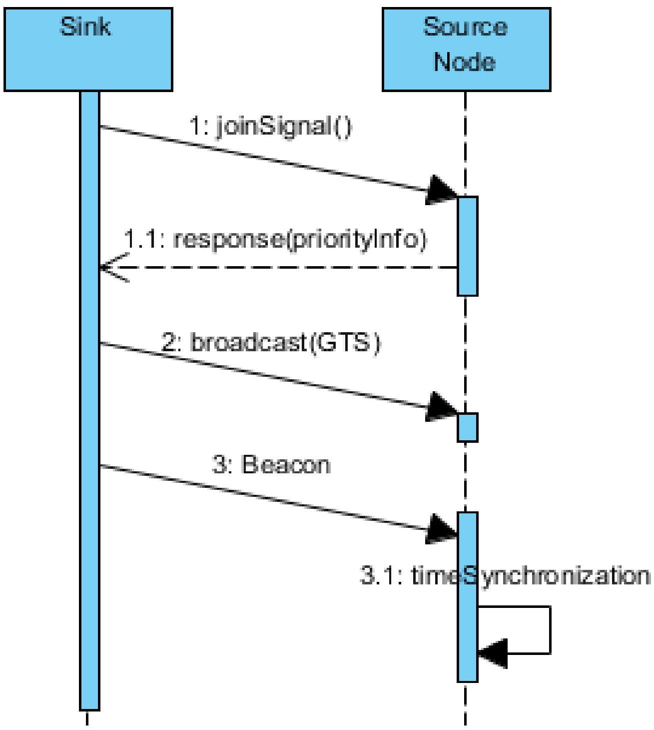

Figure 1. shows how the sink node coordinates to the source nodes and gathers priority information for the assignment of GTS slots.

Figure 2 indicates that how no-priority nodes contend for the channel access in CAP window. They perform two times CCA. The operational flow of the no-priority nodes and high priority nodes is depicted in fig. 2 (a) and fig. 2 (b), respectively. The general view of content based protocol shows that how no-priority nodes contend for the media access. At another end, the high priority nodes are already defined with dedicated slots. Therefore, there is no need to fight for access the channel.

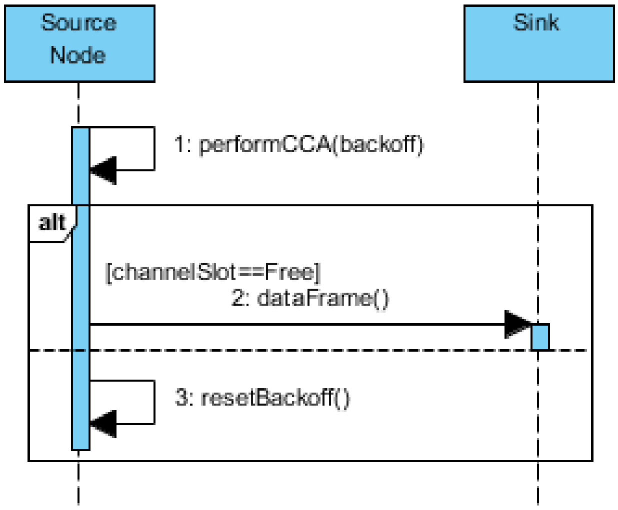

Figure 2(a). Contention-based transmission behavioral view of the no-priority nodes.

The source nodes do not face any delay in data frame transmission because nodes wake up in assigned slot and go into sleep mode when it timer gets over.

B. Priority-based Algorithm

In algorithm 1, the base station operations are described in detail. The base station acts as a controller of the complete network. Initially, the base station broadcasts join message to all source nodes.

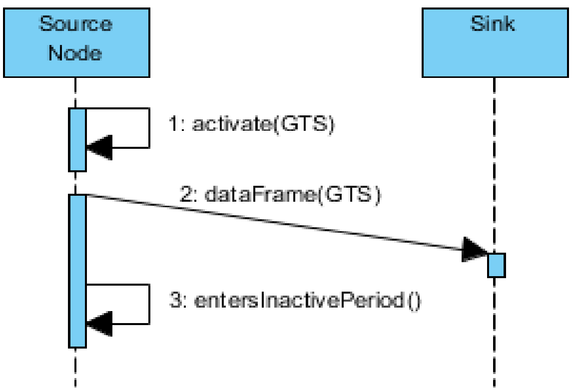

Figure 2(b). Contention Free transmission behavioral view of high priority nodes.

The each source node supposed to send the priority information to the base station so that it will decide the slot allotment to the node. The nodes which report the 1 priority bit information are considered for the CFP (contention free period) window. These nodes are sorted on First-Come-First-Served (FCFS) basis for allocating a specific slot time.

Algorithm 1: A Slotted CSMA/CA using priority bit at base station

Input: s_i

Output: slot allocation

Prerequisites: star topology, priority assignment

Begin

1. send(control_pkts); //getting node information
2. receive(priority_info); //from source nodes
3. allocate_slot(); //only to seven nodes
4. broadcast(slots); //intimation to all source nodes
5. foreach superframe
6. do
7. beacon();// synchronization with base station
8. collectDataFrame();
9. while($total_{slots}$!= ($16+t_{inactiveSlots}$))
10. end of superframe

End

The base station assigns the seven slots to first seven high priority nodes for the first superframe, however; other nodes have to compete for the slot during CAP i.e. contention access period. Afterward, the base station broadcasts the slot information to all active nodes. Furthermore, it sends the beacon signal in order to synchronize the source nodes. After reception of this information, all nodes are supposed to set their time so that the backoff boundary will be aligned with superframe slot time. The source nodes immediately contend for media access after beacon slot. The base station receives data frames until CFP window expires. After that, it goes into the sleep state.

Algorithm 2: A Slotted CSMA/CA using priority bit at source & hops

```
Input: s_i
Output: slot allocation
Prerequisites: star topology, priority assignment
Begin
Common for all nodes
do
synchronize(beacon);
CAP period (no-priority node )
if ((n ∈ n_np), s_i)
  sense_channel(T_bkoff)//maximum 9 slots
  perform (t_cc); // two times
  transmit(n_np,t_slot);
else
reset(T_bkoff);
end if
t_slot++;
while (t_slot!=9)
end do-while loop
CFP period begins (priority node )
(consider t_gts ← t_slot)
do
if ((n ∈ n_p), s_i)
  transmit(n_p , t_gts); //7 slots are assigned prior in
t_gts++;
while(t_tgs!=16)
end do-while loop

End
```

The algorithm 2 explains the flow of CAP and CFP from source node point of view. Once source nodes are synchronized with beacon time slot then CAP window get activated. The no-priority nodes start contending for the channel access. It gives the call to PHY layer to perform two times CCA method to sense the channel. If it gets channel free, then the particular node takes hold and start transmitting the data in that slot. In this window, total nine slots are available; therefore, nine nodes can deliver their data frames. However, if it fails to gain the channel access at that time, it resets its backoff timer and waits until it becomes zero.

As soon as CAP periods are over the CFP first gets activated. The node that is already got this time slot that node starts transmitting the data frame without any network overheads of channel access. This is a significant advantage against the CAP. The delay to gain the channel access is null. Here, total seven slots are available called as Guaranteed Time slots for high priority nodes. They do not experience the delay for accessing the channel as they are already got confirmation of time slot and synchronized well in advance before commencement of CFP period. Next, the idle period is commenced where each node goes into sleep state till next beacon comes. This is also called as power saving mode. This is repeated to each superframe.

PERFORMANCE ANALYSIS

The network area is 500x500m2 setup for evaluating the proposed work. The number of source nodes is 101 over multi-hop topology. To validate the results it is tested over different simulation time (75,100,125,150,175,200seconds). The transmission range of every source node is set to 30meter. The buffer length is set to 50 packets. The transmission power for sending the packet is configured to 0.660w and for receiving the packet is set to 0.395w. The initial energy of every node is set to 15J. The priority approach is implemented by modifying the existing CSMA/CA protocol [18].

The objective is to deliver the priority-based data frame transmission first over the regular traffic of the network. Furthermore, the protocol also mitigates the long delay experience of the source node that situated far away from the base station. Besides, this would be useful for delay sensitive application in the multi-hop sensor network. The results which are reported in this paper is the average of five experiments to prove its accuracy over different simulation time. The various performance parameters are examined particularly; packet delivery ratio (PDR), network delay, goodput, energy consumption, and the average hop counts in every experimentation setup. Fig. 3 shows the average packet delivery ratio approximately 78% whereas for, FCFS mechanism, it is noted around 76%. The average difference is observed around 3%. The projected each point is the average of five experimentation of the same setup. In particular, it seen that it does not cut down the packet delivery ratio of the standard CSMA/CA protocol. Moreover, the long distance traffics were served first over the regular traffic as they hop by hop towards the sink node. It is hampered by regular traffic when their hop counts are same. The packet delivery ratio is not hampered by increasing the simulation time.

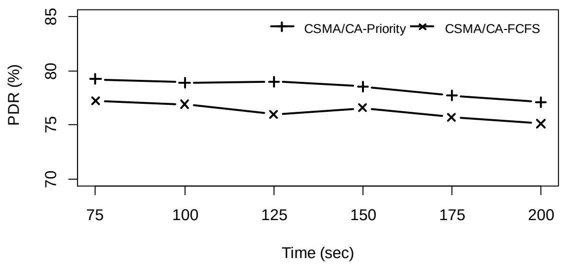

Figure 3. The analysis of packet delivery ratio of 101 nodes

The variation is noted only around 3% which is almost equal to the standard CSMA/CA protocol. Hence, it projects the good analysis specifically for delay sensitive i.e. priority-based traffic in heterogeneous wireless sensor networks. Fig. 4 depicts the average propagation time i.e. delay of different time in the same configuration. Due to priority approach, it is noted down that the propagation time is reduced significantly for long distance source nodes. Although the experimentation time has been taken variable; still protocol succeeds to keep it around 0.017 seconds using priority approach whereas using FCFS it goes around 0.019 seconds.

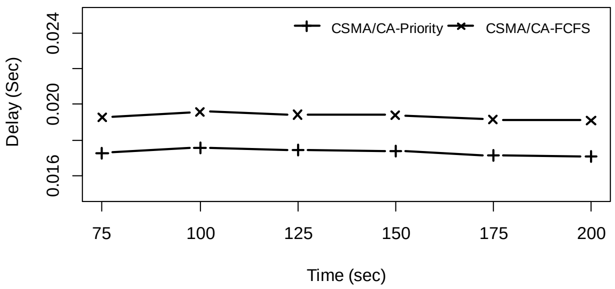

Figure 4. Analysis of delay over variable simulation time for the same setup

This shows that significant improvement is highlighted by the priority approach without hampering the core operations of the traditional of CSMA/CA protocol. Fig. 5 illustrates the analysis of energy consumption over the set of experiments with different simulation time. The power utilization is directly proportional to the simulation time as shown in the figure. The energy consumption over 75 seconds experiment is approximately 2 joules.

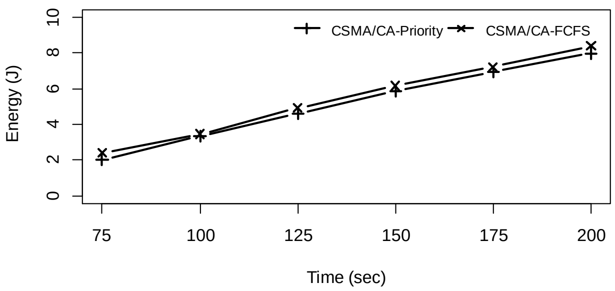

Figure 5. Illustration of energy consumption with variable time

In the end, with 200 seconds duration, the energy consumption of priority approach is going around 8 joules whereas using FCFS approach it is noted around 9 joules. Fig. 6 shows goodput performance of the proposed priority scheme with a variable period. Approximately, 27000 bits are delivered per seconds using priority approach whereas using FCFS approach it goes around 25000 bps. It is observed that the performance of priority scheme is unaffected by time fluctuations.

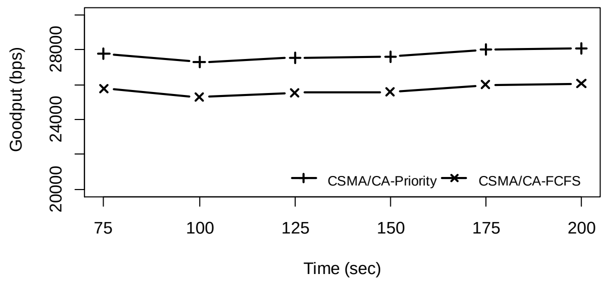

Figure 6. Shows the performance of priority-based approach regarding goodput analysis.

The goodput is shown better due to less packet loss of long distance nodes that are handled on a priority basis.

CONCLUDING REMARKS

This paper presents the performance analysis of the priority-based approach for reliable data transmission using the slotted CSMA/CA MAC protocol for IEEE 802.15.4 sensor network. The reported analysis shows that it does not affect the performance of the sensor CSMA/CA protocol. The packet delivery ratio is validated by varying the number of hops and simulation time. The goodput illustration shows significant performance over the multi-hop network. The delay of long distance source nodes is also recorded low compared with traditional data transmission approach. The tight time bound delay may be considered for the enhancement of priority-based data transmission mechanism using slotted CSMA/CA protocol.

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