QoS for Wireless Sensor Networks: Service Differentiation at the MAC Sub-Layer

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Abstract. Providing service differentiation in wireless sensor networks while proposing simple and highly scalable solution is a challenging problem. We retain the use of CSMA/CA as access protocol because of its simplicity, versatility and good scalability properties. We developed CoSenS on the top of it to address its weaknesses while facilitating the implementation of scheduling policies. In this article, we propose a simple and scalable service differentiation solution; we implement fixed priority and earliest deadline first on the top of CoSenS. The simulation analysis shows that our solution greatly enhances end-to-end delay, reliability and deadline meet ratio for urgent traffic while not degrading best effort traffic compared to IEEE 802.15.4 original protocol and IEEE 802.15.4 implementing these scheduling policies.

Keywords: wireless sensor networks, QoS, scheduling, csma/ca, MAC protocols.

1 Introduction

Many sensor applications require quality of service (QoS) support in the communication stack they use in order to work properly. These requirements include but are not limited to reliability, end to end delay and service differentiation. Most of the proposed solutions are TDMA based [7]. However, the use of TDMA scheme needs careful network configuration for efficient time-slot allocation and it is not scalable in general for large scale WSN and not robust for automatically adapting to the changes in the network (nodes mobility and death, environment changes, *etc*).

CSMA/CA is a well known access protocol. It is simple to implement and does not need any synchronization between nodes. This makes it a suitable choice for WSN. CSMA/CA performs well in light traffic mode but the performance quickly degrades in heavy traffic (lack of reliability, high end-to-end delays and low throughput). This makes it not suitable for QoS.

To address QoS offer, we propose firstly CoSenS, a simple MAC layer protocol, which is implemented on the top of CSMA/CA to overcome its weaknesses. The idea of CoSenS is that a router does not retransmit packets as they arrive. Instead, it collects data from its children and other neighbor routers and then sends them into a burst during a period of time that we call transmission period. The performance analysis shows that CoSenS greatly enhances throughput, end to end delay and reliability. In addition,

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since packets are queued at the router, CoSenS allows us to design efficient scheduling algorithms for providing differentiated QoS.

Finally, for service differentiation, we propose two scheduling policies that we implemented on the top of CoSenS. The first one is a fixed priority scheduler. We consider two types of traffic; periodic traffic and event driven traffic which has higher priority. The second one is Earliest Deadline First (EDF). We suppose that some deployed applications provide a deadline for their data in order to work properly.

The organization of this paper is as following. The related work is given next. CoSenS is described in Sec. 3. Section 4 describes the proposed scheduling policies. In Sec. 5 we present the simulation results. Section 6 concludes the paper.

2 Related Work

An implicit prioritized access protocol (I-EDF) [1] is designed especially for hard real time. A cellular backbone network is adopted and different frequency channels are assigned. In a cell, time is divided into frames and all nodes are frame synchronized and follow earliest deadline first (EDF) schedule for packet transmission to guarantee bounded delay. A capable router node is required at the center of each cell and equipped with two transceivers for separate transmission and reception. Inter-cell communication is supported by a globally synchronized TDMA scheme and the messages are ordered by their earliest deadlines too. The mixed FDMA-TDMA scheme offers a collision-free solution. Simulations show that I-EDF can provide high throughput and low latency even in heavy loads. However, the system architecture and requirements appear impractical for WSNs. Nodes are assumed synchronized. Routers need to be deployed specifically following the cellular structure and topology knowledge is required.

PEDAMACS [2] is a TDMA-based MAC protocol that aims to achieve both energy efficiency and delay guarantee. It considers a special class of sensor networks with high powered access point (AP) which can reach all nodes in one hop and with nodes periodically generating packets. Topology information is gathered by AP and a scheduling algorithm is then adopted to determine when a node should transmit and receive data. PEDAMACS guarantees bounded delay and eliminates network congestion. However, the requirement of powerful AP has restricted the protocol to only few applications and reduced its attractiveness.

Munir et *al.* [3] addressed link burstiness and proposed a scheduling algorithm which bounds the latency of a set of periodic streams while providing 100 % of data reliability over bursty links. The protocol used a TDMA like mechanism for data transmissions.

GTS mechanism of IEEE 802.15.4 [4] and its various enhancements like i-GAME [5] are also possible solutions for providing QoS support in WSN. In the beacon-enabled synchronized mode, the PAN coordinator may allocate portions of the active superframe to form guaranteed time slots (GTSs). The major drawback of this mechanism is that only seven nodes can request GTS allocations. i-GAME solves this problem by letting multiple nodes share the same GTS. An admission control algorithm is used then to accept time slot requests if the requirements do not exceed available resources.

Although the use of TDMA schemes ensure deterministic performance, it still needs careful network configuration for efficient time-slot allocation and it is not scalable in general for large scale WSN and not robust for automatically adapting to the changes in the network. Our aim is to develop much simpler solution which does not require any configuration effort and can self adapt to the dynamic network evolutions.

Koubaa et *al.* [6] proposed a differentiated MAC protocol in which traffics are categorized into high and low priority queues which employ different CSMA/CA settings. The result offers a heuristic solution to provide different QoS for messages of different priorities. This solution is only suitable for light traffic environment because the performance of CSMA/CA on which this solution is based quickly degrades in heavy traffic load.

A full survey about Real time QoS support in WSN can be found here [7].

We retain the widely spread CSMA/CA protocol for its simplicity and good scalability properties and implement CoSenS on the top of it. CoSenS addresses at the same time CSMA/CA's drawbacks and enables the implementation of scheduling policies such as EDF or fixed priority. Thus our scheme is scalable because it does not require any synchronization between nodes. In addition, CoSenS performs well in medium and heavy network load where delivering critical data reliably and rapidly to the sink is more important.

3 CoSenS

3.1 General Description

We consider a 2-tiers architecture network composed of routers to which are associated simple nodes (typically FFD and RFD of ZigBee [8]). A simple node is a device that generally has measurement sensors built in and has limited routing decisions capabilities. A router is a device that implements full routing and network management protocols. However, it can also act as a simple device when its routing and management capabilities are disabled.

A simple node is associated to a router. In that case, the association forms a child-father relation where the child is the simple node and the father is the router. We consider the case where every simple node has only one father. A router can be associated with more than one child and all routers form an ad-hoc network. In this case, any routing protocol, like AODV or "Hierarchical Tree Routing" (HTR) of ZigBee for instance, can be used to establish routes between routers[1]. So, if a simple node wants to send data to a receiver node, it simply forwards them to its father. Besides, all requests like obtaining information about a destination are also addressed to the father.

The basic medium access protocol for all nodes (simple nodes and routers) is CSMA/CA but with different parameters for each type of node. We used the unslotted version proposed by IEEE 802.15.4 standard. CoSenS is implemented on the top of CSMA/CA protocol. It is enabled for routers and disabled for simple nodes by default (in the rest of the section, routers are used to describe CoSenS operating mode). The MAC layer operates on the top of the "2450 MHz DSSS IEEE 805.15.4" physical layer. The data rate is equal to 250 kb/s.

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[1] In the simulations, we used HTR.

3.2 Energy

In this work, we suppose that routers do not have severe energy constraints. This is a reasonable assumption in many real-world deployment scenarios, like building monitoring systems, monitoring of industrial environments or patient monitoring in hospitals. In the latter scenario for example, the patient carry simple nodes to monitor its vitals. These simple nodes transmit data to a router located in the room. All routers in the hospital form an ad-hoc network and transmit data to the sink. Simple nodes, are battery supplied. Hence, energy efficiency have to be taken into account for these nodes. Since no synchronization is required for simple nodes using CoSenS, they are always in sleep unless they have a message to send. However, a first extension of CoSenS has been already done to tackle energy and throughput tradeoff [9].

3.3 Basic Rules

CoSenS has four basic rules. First, routers have the priority to access the medium over simple nodes. This is done by setting lower backoff exponent value (which is a parameter of CSMA/CA). Second, a router does not transmit packets one by one upon their arrival. Instead, it waits for a period of time, WP, and collects data either from its children or from its neighbor routers. Third, after the end of the WP, the router starts transmitting all packets queued in its buffer in a single burst during the TP. Finally, at the end of the TP, the router starts another cycle and goes again to the waiting for reception state. WP and TP are illustrated in the example given by the Fig. 1.

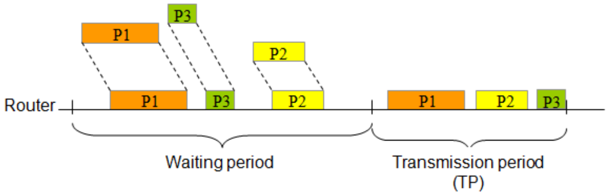

Fig. 1. An example of how CoSenS works

Note that since simple nodes use CSMA/CA, they transmit data during the WP of their respective fathers because the channel can be free only during that period (CSMA/CA checks the channel status before transmitting).

3.4 Transmission Period

The collected data during the waiting period are transmitted in a burst. CSMA/CA protocol is used to transmit only the first packet. Then, the remaining packets are directly transmitted upon the reception of the acknowledgement (*ack*)[2]. If an *ack* is not received, the transmitted packet is retransmitted using CSMA/CA protocol again. Burst

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[2] Acknowledgments are enabled in CoSenS.

transmission resumes if the packet is successfully transmitted; The remaining packets will be sent directly after the reception of the *ack*.

TP has a variable duration which depends on the number of collected packets during WP and the eventual retransmissions. We note that all queued packets are transmitted during the current TP. So, the next WP will start with an empty queue.

The use of CSMA/CA for the first packet to transmit ensures also that the TPs of neighbor routers do not collide. In fact, if a router does not win the access to the medium at the beginning of its TP, its WP is extended until the end of the TP of the transmitting router.

3.5 Waiting Period

The length WP depends on the amount of incoming traffic; the higher the traffic volume is, the longer the WP is.

Consider the example of a waiting and transmission cycle given by the Fig. 2. Intuitively, CoSenS performs better than CSMA/CA if the sum of the idle delays in the WP plus one Backoff Period (BP) (of the first transmitted packet in the TP) is lesser than the sum of the BPs which will be generated at the transmission of the received packets if CSMA/CA is used (1). Hence WP must satisfy the condition given by (2).

In (1), N_{pkts} is the number of received packets during the WP and $pktSvcT_i$ is the service time of packet i.

$$\sum_{i=1}^{N_{pkts}} BP_i \geq WP - \sum_{i=1}^{N_{pkts}} pktSvcT_i + BP_{TP} \tag{1}$$

$$WP \leq \sum_{i=1}^{N_{pkts}-1} BP_i + \sum_{i=1}^{N_{pkts}} pktSvcT_i \tag{2}$$

$$= \sum_{i=1}^{N_{pkts}-1} BP_i + sumSvcT \tag{3}$$

WP is adapted at runtime as follows. N_{pkts} and $sumSvcT$ are estimated at each cycle. Then, WP is set according to (4). $\overline{BP}$ is given by 5 where $aUnitBackoffPeriod = 0,32$ ms (a constant defined in IEEE 802.15.4 standard) and $macMinBE = 2$.

$$\overline{WP} = (\overline{N_{pkts}} - 1) \cdot \overline{BP} + \overline{sumSvcT} \tag{4}$$

$$\overline{BP} = 2^{macMinBE-1} \cdot aUnitBackoffPeriod \tag{5}$$

The Estimation Algorithm: Let's define the set $\Omega \in \mathbb{N}$ as the set of WPs during which the router receives data and WP_k, $k \in \Omega$ these WPs. Let us denote by $\overline{sumSvcT}$ and $\overline{N_{pkts}}$ the exponential moving average of $sumSvcT_k$ and N_{pkts_k}, $k \in \Omega$, respectively.

$$\overline{sumSvcT_k} = (1-\alpha) \cdot \overline{sumSvcT_{k-1}} + \alpha \cdot sumSvcT_{k-1} \tag{6}$$

$$\overline{N_{pkts_k}} = (1-\alpha) \cdot \overline{N_{pkts_{k-1}}} + \alpha \cdot N_{pkts_{k-1}} \tag{7}$$

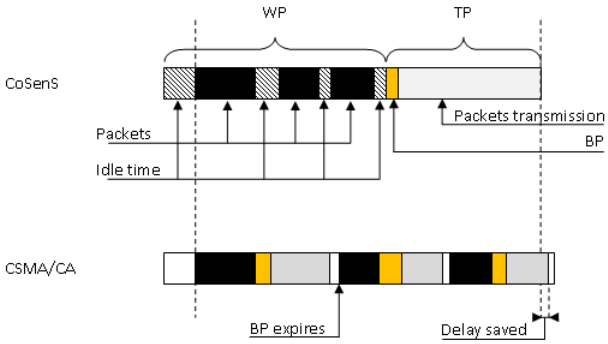

Fig. 2. Comparison between CoSenS and CSMA/CA. "Backoff expires" corresponds to the expiration of the backoff timer for the transmitting node. In CoSenS, it is included in the idle time.

α is the smoothing factor. We used a non linear filter where α is bigger when $sumSvcT_{k-1} \geq \overline{sumSvcT}_{k-1}$ in (6) and $N_{pkts_{k-1}} \geq \overline{N}_{pkts_{k-1}}$ in (7) allowing these two values to adapt more swiftly to traffic increase. $\overline{N}_{pkts_k}$ and $\overline{sumSvcT}_k$ are evaluated before the beginning of the k^{th} WP and then used in the Algorithm 1 to determine the duration of the k^{th} WP.

Algorithm 1. Estimation algorithm

```
/* Update $\overline{N}_{pkts_k}$ and $\overline{sumSvcT}_k$*/
/* $\alpha$ is set according the the $k^{th}$ value */
$\overline{sumSvcT}_k = (1-\alpha)\cdot\overline{sumSvcT}_{k-1} + \alpha\cdot sumSvcT_{k-1}$;
$\overline{N}_{pkts_k} = (1-\alpha)\cdot\overline{N}_{pkts_{k-1}} + \alpha\cdot N_{pkts_{k-1}}$;

/* Update WP */
$\overline{WP}_k = (\overline{N}_{pkts_k} - 1)\cdot\overline{BP} + \overline{sumSvcT}_k$
$WP_k = \max(WP_{min}, \min(\overline{WP}, WP_{max}))$
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4 Packet Scheduling Policies

4.1 Fixed Priority

In this packet scheduling policy, we consider two types of traffic; periodic and event-driven. Hence, we have 2 priorities. We consider that event driven traffic has higher priority. Generally, an event corresponds to a measure of a physical phenomenon which is different from the normal value. Thus, these events must be transmitted as quickly as possible and as reliably as possible. Periodic data corresponds to periodic updates which report no or minor fluctuations of the measured phenomenon. We consider that this type of data is delay tolerant.

Event-driven data are transmitted first. The transmission of packets which are classified as periodic occurs after the transmission of all event-driven data. For each traffic class, packets are served according to their order of arrival.

4.2 Earliest Deadline First

Some applications may require a deadline to packet's end-to-end delay. In this case, EDF is a suitable solution.

We define t_p^{rem} as the remaining time until the deadline of packet p expires. It is included in the packet header. The application at the source node initializes this variable with the deadline. Then, it is updated at each hop to account for queuing, contention, and transmission delays. We define $prio_p^R$ as the priority of packet p calculated by router R (8).

$$prio_p^R = \frac{1}{t_p^{rem}} \tag{8}$$

Upon packet's reception, the router calculates its priority and inserts it to the queue according to this priority; higher priorities are transmitted first. Hence, the waiting time of a packet at the receiving router is not taken into account immediately for priority calculation. We note that the packets that do not provide or have missed their deadlines are scheduled at the tail of the transmission queue according to their order of arrival. In the original version of EDF [10], packets which miss their deadlines can still be scheduled near the queue head. This delays further the transmission of queued packets which increases the missed deadline ratio especially in an overloaded network.

t_p^{rem} is updated at each router when it acquires the channel and is about to transmit, as follows. First, it time-stamps the packet when it is received and when it becomes the head of the queue to account for queuing delay, t_p^{qdel}. The router calculates then the contention delay (caused by CSMA/CA), t_p^{cont}, and the transmission delay, t_p^{tr}. In case of retransmission due to packet or acknowledgment loss, the router shall update t_p^{cont} and t_p^{tr} to account for these additional delays. In this case, the acknowledgment delay has to be taken into account also (added to t_p^{cont}). Propagation delays are ignored as their values are negligible in comparison with queuing and transmission delays. Finally t_p^{rem} is updated as follows:

$$t_p^{rem} = t_p^{rem} - t_p^{qdel} - t_p^{cont} - t_p^{tr} \tag{9}$$

We note that t_p^{rem} is computed locally at each node and does not require any global time synchronization.

5 Simulation Results

We present a comparative study of CoSenS with IEEE 802.15.4 using the unslotted version of CSMA/CA (denoted IEEE 802.15.4 in the rest of the document) . FP and EDF scheduling policies (in addition to FIFO) are implemented on both protocols. The metrics used are *end to end delay*, *successful transmission rate* (STR) and *deadline meet ratio* (DMR). The end to end delay is equal to the average end to end delays of all successfully received packets by the receivers application layer. The STR is equal to the total number of successfully received bits by the receivers application layer divided by the total number of generated bits by all nodes application layer. The DMR is defined

Table 1. General simulation parameters. CSMA/CA parameters are used by CoSenS and IEEE 802.15.4.

Variable			value
PHY	data rate		250 kb/s
	Coverage	simple node	$\sqrt{2}\cdot 100$ m
		Router node	200 m
Packet length	APL		402 bits
	MAC		500 bits
CSMA/CA	*macMinBE*	simple node	3
		router node	2
CoSenS	α	α_1	0.08
		α_2	0.1
	WP	WP_{min}	0.001 s
		WP_{max}	0.07 s
Zigbee Tree Routing parameters	Cm		12
	Rm		5
	Lm		6
Simulated duration			6 min

as the number of packets which meet their deadlines divided by the number of received packets. The general simulation parameters are summarized in Table 1. The simulator used is OPNET[11] (Modeler v15.0.A PL3).

5.1 Network and Scenarios Description

Network: We consider a multi-hop network composed of 25 routers and 125 simple nodes deployed in a 1000x1000m^2 sensor area. The nodes are organized as shown in Fig. 3. The sensor area is divided in 25 equal squares. For each square, one router is located at the center and five nodes are randomly deployed. The routing protocol used is the ZigBee HTR protocol. The simulation duration is equal to six minutes; the first minute is reserved for node association and the remaining five minutes for data generation and transmission. This network represent a patient monitoring system or an equivalent system as suggested in Sec. 3.2.

Scenarios: The first set of simulations compare the intrinsic performance of CoSenS and IEEE 802.15.4 using only Periodic or Poisson traffic. In the second set of simulations three scenarios are simulated. In each one, a group of 10%, 25%, and 50% of the total number of nodes is randomly selected and generates only Poisson traffic with a inter-arrival time equal to 1s. The rest of nodes generate Periodic traffic. Poisson traffic is considered as event traffic and has higher priority. For each scenario, five simulations are conducted and a different group of nodes is randomly selected each time. The results are then averaged. In all scenarios, we varied the intensity of periodic traffic and studied the performance of both protocols using FIFO, FP and EDF. In both sets, all nodes send data to the root node located in the center of the network. The third set of simulation compares the performance of CoSenS and IEEE 802.15.4 using EDF in the following scenario. For each event generated by a simple node, the Root node issues a response event to it. These response messages represent the actions the monitor of the network takes in response to an event.

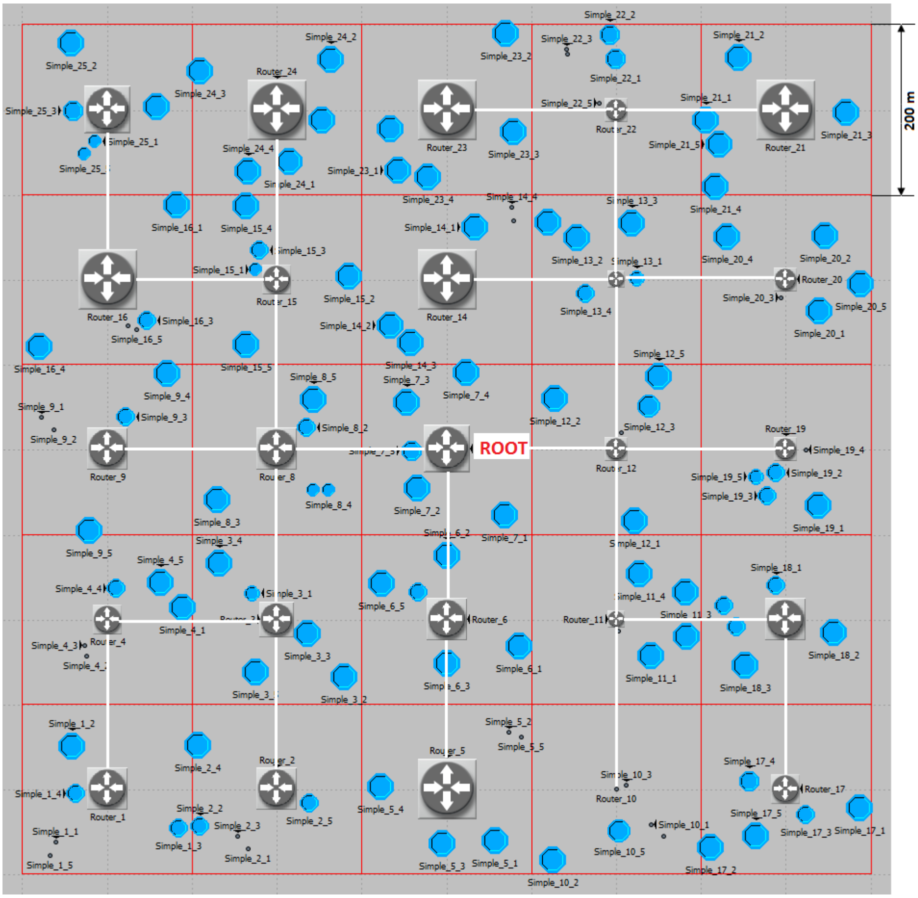
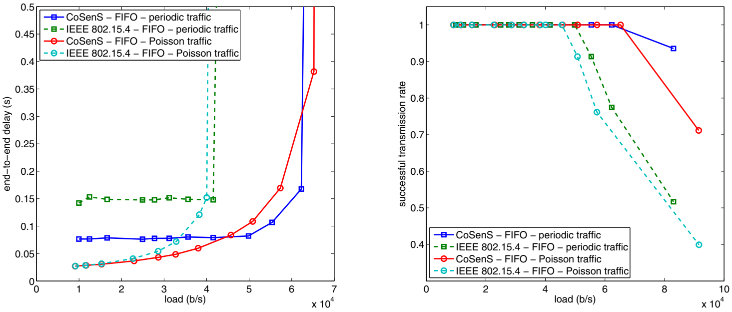


Fig. 3. Simulation network. Blue discs represent simple nodes. White lines correspond to the formed tree between routers (router-simple nodes association is not drawn). The root node is located in the center of the network.

5.2 Results

Hereafter, we present the results of the three sets of simulations.

Intrinsic Performance: Figure 4(a) shows the end-to-end delay performance as a function of the total load generated by the application layer (sum of event and periodic traffic load). We note that in the rest of the figures, we used this definition for the load. The performance of CoSenS protocol is better for both types of traffic. In the case of a Poisson traffic, IEEE 802.15.4 and CoSenS obtains similar end to end delays for light traffic. After that, CoSenS outperforms IEEE 802.15.4. As far as the load increases, the difference in terms of end to end delay becomes more and more obvious. In fact, as the load increases, the router collects many packets and then transmits them in burst during the TP. This minimizes the transmission time (CoSenS uses CSMA/CA only for the



(a) End-to-end delay. (b) Successful transmission rate.

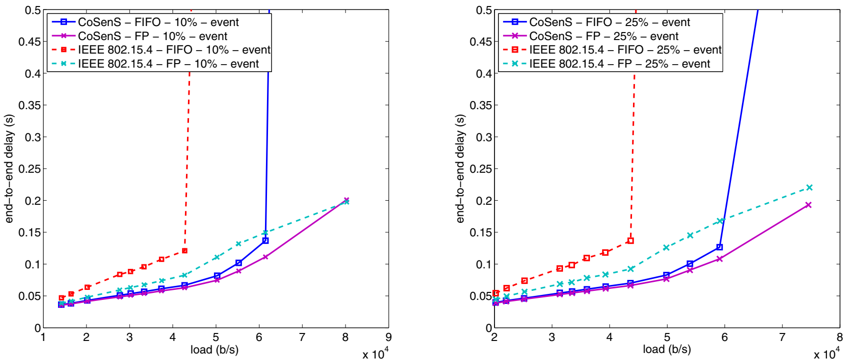
Fig. 4. End-to-end delay and successful transmission rate comparison between CoSenS and IEEE 802.15.4 using Periodic and Poisson traffic

first packet). In addition, the *WP* is adapted according to the incoming traffic. Hence, the idle time (where the router is not receiving data during the WP) and the transmission time are minimized. This explains the good performance of CoSenS. For Periodic traffic, CoSenS always outperforms IEEE 802.15.4. In fact, the 125 nodes generate periodic traffic with an initial offset randomly selected between [0,1). For example, if the period T is greater than 1 second, a packet is generated each 0.008s in average between [T,T+1). Hence, the network is momentarily overload at each period. Since CoSenS quickly adapts the WP (due to the non linear filter that we used), it takes advantage of the situation; many packets are collected which ameliorates the end-to-end delay like explained for Poisson traffic. The saturation load for CoSenS and IEEE 802.15.4 are reached around 50 kb/s and 75 kb/s, respectively. The performance of both protocols falls after that.

For STR (Fig. 4(b)) both protocols obtain 100% before their respective saturation point. This is due to the acknowledgment mechanism. The performance fall after that but CoSenS obtains better results.

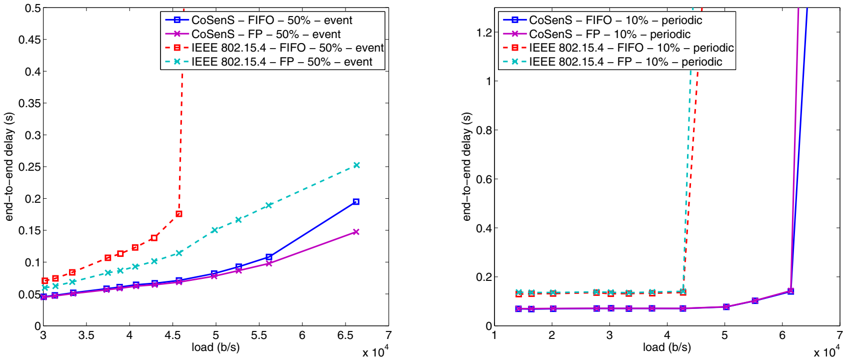
CoSenS and IEEE 802.15.4 with Scheduling Performance: Figures 5(a), 5(b) and 5(c) show the end-to-end delays of event data for the three scenarios. The performance of event traffic is greatly enhanced using FP for both protocols. IEEE 802.15.4 with FP performs well in case of low event traffic load (10% of nodes generating events). In fact, as the load increases, the routers in IEEE 802.15.4 become the network bottlenecks because the packets can easily be transmitted to them (the maximum MAC throughput of CSMA/CA is around half the MAC data rate, 125 kb/s). Since the event traffic is relatively small compared to periodic traffic and is always inserted at the queue head, its end-to-end delay is small. However, the performance decreases as the event load increases (25% and 50% of nodes generating events).

CoSenS with FP almost always obtains better results than IEEE 802.15.4. Also, it efficiently schedules events in low event traffic load scenario leading to a better end-to-end delay compared to FIFO version. In addition, the performance increases as the event



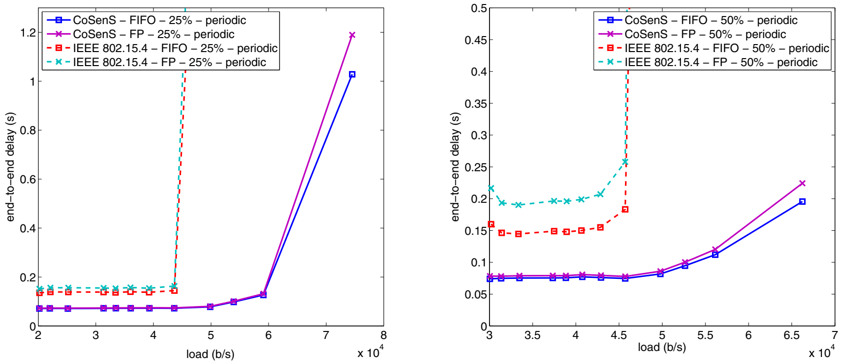
(a) Event traffic delay - 10% case.

(b) Event traffic delay - 25% case.



(c) Event traffic delay - 50% case.

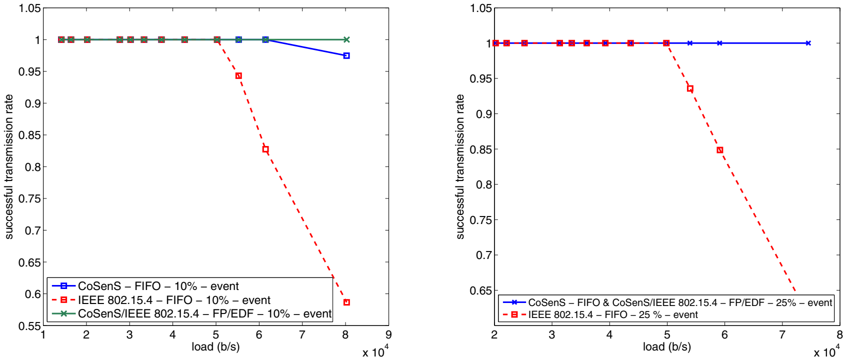
(d) Periodic traffic delay - 10% case.



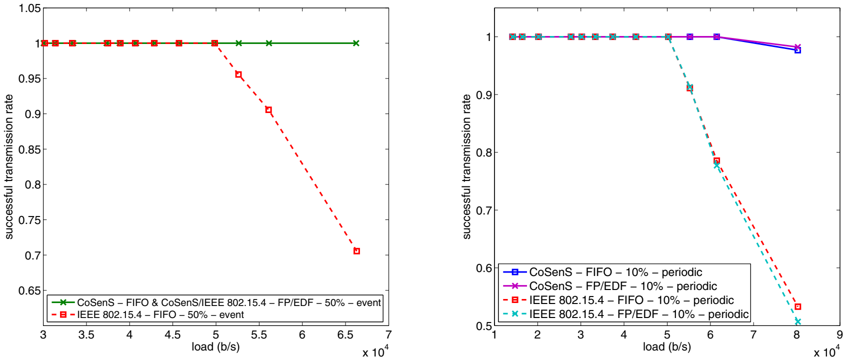
(e) Periodic traffic delay - 25% case.

(f) Periodic traffic delay - 50% case.

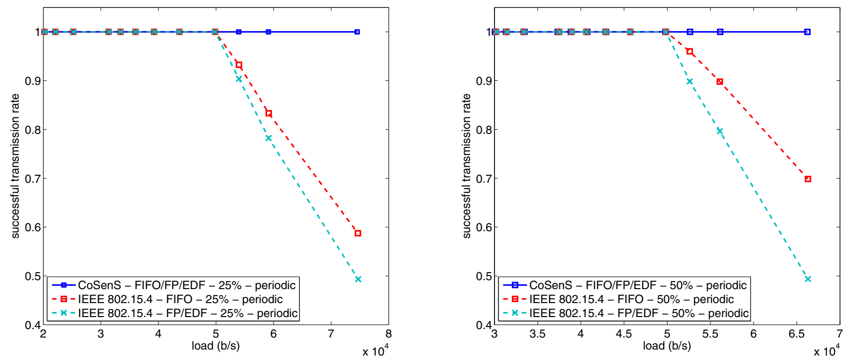
Fig. 5. Event and Periodic end-to-end delays comparison between CoSenS and IEEE 802.15.4 using FIFO and FP scheduling policies



(a) Event traffic STR - 10% case.
(b) Event traffic STR - 25% case.



(c) Event traffic STR - 50% case.
(d) Periodic traffic STR - 10% case.



(e) Periodic traffic STR - 25% case.
(f) Periodic traffic STR - 50% case.

Fig. 6. Successful transmission rate comparison between CoSenS and IEEE 802.15.4 using FIFO, FP and EDF scheduling policies. Here, points which are greater than 0.99 are ceiled.

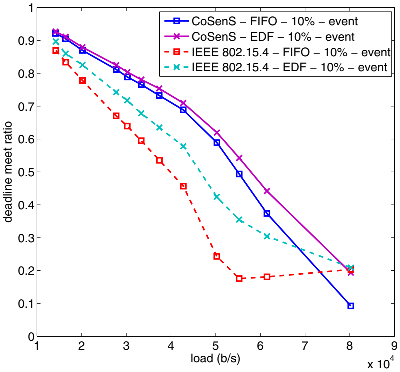
traffic load increases. This is due to two factors. On one hand, CoSenS performs well below its saturation load. On the other hand, the total load decreases below the saturation point of CoSenS as the event load increases. This is because each selected node generate a traffic with a constant inter-arrival time.

Figures 5(d), 5(e) and 5(f) show the end-to-end delays of periodic data for the three scenarios. The results show that the FP scheduling policy does not degrade too much the end-to-end delay of periodic data for both protocols. The results in Fig. 5(d) are similar to the intrinsic performance results since the event data is low. CoSenS obtains better results than IEEE 802.15.4. Thus, CoSenS can handle high event loads more efficiently in terms of end-to-end delay while not degrading much the performance of periodic data. This makes it a good choice for QoS support in WSN.

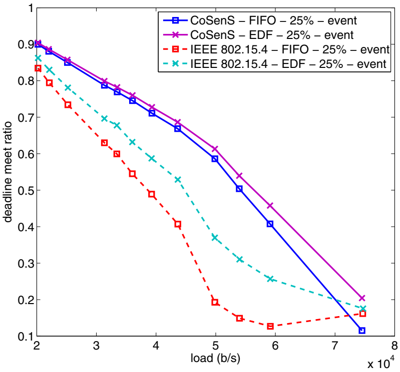
The results of STR for event data are illustrated in Figures 6(a), 6(b) and 6(c). Using FP and EDF greatly enhances the performance of both protocols in comparison with FIFO; they obtain 100% in all event load cases. However, for IEEE 802.15.4, this performance is reached at the cost of an additional degradation of the performance of periodic data. In fact, we observe in figures 6(d), 6(e) and 6(f) that increasing the event load decreases the STR of periodic data after the saturation load when using FP or EDF. Before the saturation load, the acknowledgment mechanism ensures a STR of 100%. CoSenS saturation point is higher than IEEE 802.15.4. Thus, the STR of event loads is enhanced with a minimum degradation of the STR of periodic data.

In order to study the DMR, we set the deadline of event data to 0.08s. This time corresponds to average delay obtained by IEEE 802.15.4 for the event data in the high event load case (50%) and the minimum generated periodic traffic. Using EDF scheduling policy enhances the DMR for both protocols in all event load cases. For IEEE 802.15.4 using FIFO, we observe that for high loads, the DMR increases. This is because the number of received packets decreases significantly (STR decreases). So there is higher chances that the arrived packets meet their deadlines. We remember that the DMR is calculated based on the received packets and not all generated packets. We observe also that the performance of CoSenS with FIFO is better than IEEE 802.15.4 one except after the saturation load. This is because the STR of CoSenS is largely greater than IEEE 802.15.4 one even after it reaches its saturation point for both types of traffic. Nonetheless, the fact that CoSenS provides good STR for periodic traffic after the saturation load may harm the DMR of event data at these loads which is not desirable. Hence, a congestion control mechanism have to be implemented to prevent such a situation. CoSenS with EDF largely outperforms IEEE 802.15.4 with EDF. We observe that below the saturation load of CoSenS, the difference between both protocols increases as the total load increases. This is due to the amelioration of end-to-end delay for medium and high loads. Moreover, CoSenS ameliorates its DMR while it falls for IEEE 802.15.4 as the event load increases (three scenarios).

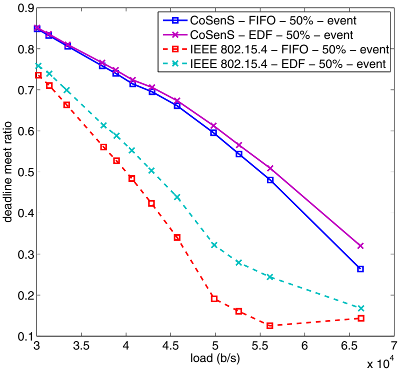
CoSenS and IEEE 802.15.4 with Response Events Performance: In this set of simulations we set the deadline of event data (both types) to 0.08s. We consider the case where a group of 10% of the total number of nodes is randomly selected and generates Poisson traffic. The results (Fig. 8) are similar to the DMR study of the first scenario (10%) of the previous set of simulations. Before its saturation load, CoSenS using EDF



(a) 10% case.

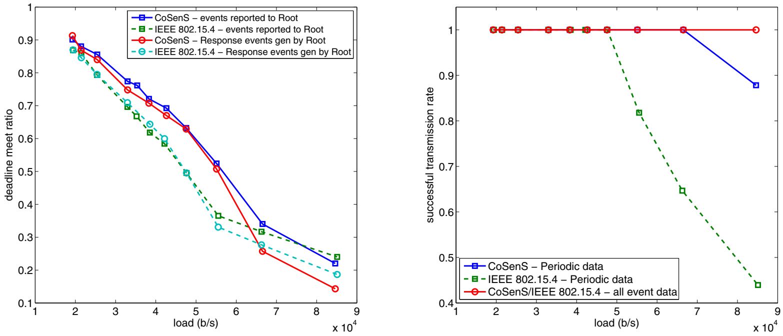


(b) 25% case.



(c) 50% case.

Fig. 7. Deadline meet ratio of CoSenS and IEEE 802.15.4 using EDF



(a) DMR of reported and generated to/by the Root events.

(b) STR of all event and periodic data.

Fig. 8. Deadline meet ratio and successful transmission rate comparison between CoSenS and IEEE 802.15.4 using EDF for response events performance

outperforms IEEE 802.15.4 using EDF for both types of events. However, its performance falls after that. Again, this is because CoSenS keeps providing better STR for periodic traffic which harms the DMR of event data. The comparison between the DMR of both types of events shows the limit of EDF scheduling policy; as the load increases, the DMR of response events become lower than simple nodes events. This is because the remaining time before deadline expiration tend to zero, and more rapidly as the load increases, as packets converge to the Root. Hence, compared to the remaining time of response event packets, they will be scheduled first. However, simple node events have fewer remaining hops than response events.

6 Conclusion

CoSenS is a simple but efficient scheme which improves the performance of the widely used CSMA/CA protocol. It efficiently handles periodic and Poisson traffic, has higher STR and lower end-to-end delay.

Using scheduling policies greatly enhances the performance of the original protocols for event traffic. The performance analysis shows also that CoSenS overall performance is better than IEEE 802.15.4. First, it increases as the event traffic load increases. Finally, CoSenS with FP or EDF does not degrade much the performance of periodic data. Certainly, this may harm the event data when the load exceeds the saturation. However, since the router in CoSenS has a complete knowledge about the collected data, it has the possibility to aggregate them which improves throughput and perform congestion control more easily; it can discard packets more efficiently. Along with an improved delay, throughput and reliability, CoSenS is a simple and elegant MAC solution for QoS support in WSNs.

Future work aim at the development of admission and congestion control mechanisms.

References

1. Caccamo, M., Zhang, L.Y., Sha, L., Buttazzo, G.: An implicit prioritized access protocol for wireless sensor networks. In: 23rd IEEE Real-Time Systems Symposium, RTSS 2002, pp. 39–48 (2002)
2. Ergen, S.C., Varaiya, P.: PEDAMACS: power efficient and delay aware medium access protocol for sensor networks. IEEE Transactions on Mobile Computing 5(7), 920–930 (2006)
3. Munir, S., Lin, S., Hoque, E., Nirjon, S.M., Stankovic, J.A., Whitehouse, K.: Addressing Burstiness for Reliable Communication and Latency Bound Generation in Wireless Sensor Networks. In: 9th ACM/IEEE Conference on Information Processing in Sensor Networks (IPSN 2010) (2010)
4. IEEE-TG15.4. Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for low-rate Wireless Personal Area Networks (LR-WPANs). IEEE standard for information technology (2006)
5. Koubâ, A., Alves, M., Tovar, E., Cunha, A.: An implicit GTS allocation mechanism in IEEE 802.15.4 for time-sensitive wireless sensor networks: theory and practice. Real-Time Syst. 39, 1–3 (2008)
6. Koubaa, A., Alves, M., Nefzi, B., Song, Y.Q.: Improving the IEEE 802.15.4 Slotted CSMA/CA MAC for Time-Critical Events in Wireless Sensor Networks. In: Workshop on Real Time Networks RTN (July 2006)
7. Li, Y., Chen, C.S., Song, Y.-Q., Wang, Z.: Real-time QoS support in wireless sensor networks: a survey. In: 7th IFAC International Conference on Fieldbuses & Networks in Industrial & Embedded Systems - FeT 2007, Toulouse (2007)
8. ZigBee Specification Document 053474r17, `http://www.zigbee.org`
9. Nefzi, B., Cruz-Sanchez, H., Song, Y.-Q.: SCSP: An energy efficient network-MAC cross-layer design for wireless sensor networks. In: IEEE 34th Conference on Local Computer Networks, LCN 2009, pp. 1061–1068, October 20-23 (2009)
10. Liu, C.L., Layland, J.W.: Scheduling Algorithms for Multiprogramming in a Hard-Real-Time Environment. J. ACM 20(1), 46–61 (1973)
11. OPNET: OPNET Simulator, v 15.0, `http://www.opnet.com`