Improving Emergency Messages Transmission Delay in Road Monitoring based WSNs

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Abstract—**The main wireless technology used for events sensing and data collection is wireless sensor devices. These sensors are mounted on vehicles or in the roadside to send data collected periodically or upon incident detection. In this latter case, ensuring low transmission delay from the detector sensor to WSNs gateway is a real challenge. Indeed, faster notification of the Traffic Management System (TMS) leads to more efficient reaction to the emergency situation. Thus, cars collision and human lives loss as well as road traffic jam will be mitigated. In this paper, we investigate the Medium Access Control (MAC) layer in WSNs to improve the real time data collection scheme. To this end, we propose an enhanced backoff selection scheme for IEEE 802.15.4 protocol to ensure fast transmission of the detected events on the road towards the TMS. The main feature of our scheme is its ability to assign a shorter waiting time for messages carrying critical information without changing the basic principle of the backoff mechanism. The obtained simulation results under various scenarios have proven the effectiveness of our scheme in terms of transmission delay reduction.**

Keywords – **Wireless Sensor Networks (WSNs), Road Monitoring, IEEE802.15.4, MAC layer protocols, Intelligent Transportation System (ITS).**

I. INTRODUCTION

Road traffic monitoring has received recently a significant attention from the research community [1] due to the ecological and economic considerations incurred by traffic congestion, accidents and air pollution. These problems impose an improvement of the existing Traffic Management Systems (TMSs) by enhancing road monitoring equipments' efficiency and accuracy, particularly in big cities where traffic congestion presents an important issue and the need for highway traffic monitoring grows. In this context, Intelligent Transportation Systems (ITS) aim to enhance the mobility, efficiency and safety through the use of communications, information processing, electronic and control technologies.

In the last decade, many projects have been launched to achieve this goal, such as PeMS (Performance Measurement System) which is a joint project between the California Department of Transportation and researchers of the University of California at Berkeley [2]. The PeMS project collects more than 1GB of data per day, stores, and analyzes data from thousands of loop detectors [5]. The intent of this project is to collect historical and real-time freeway data from freeways in the state of California in order to compute traffic performance measures. The project integrates a wide variety of information for example: incidents, lane closures, toll tags, vehicles classification .... Another project named PATH (Partners for Advanced Transit and Highways) conducted at the same university, replaces the traditional data collection methods with Wireless Sensor Networks (WSNs). PATH focuses on the prototype design, analysis, and performance of WSNs for traffic monitoring using both acoustic and magnetic sensors [5].

Besides sensors and induction loops, the cameras have been also installed along side the highways and junctions to report pictures or videos regarding the state of traffic. However, cameras and inductive loops are considered as bulky and power-hungry solutions. In addition, most of these existing data collection tools are connected through copper wires or optical fibers to central data processing, which are costly to install and maintain. Moreover, these solutions turn out to lack of flexibility in terms of evolution of the deployed architecture. Furthermore, the video cameras cannot work well under bad weather conditions due to the limited visibility.

WSNs represent an emerging technology which can be employed to overcome the above limitations. This solution is a distributed collection of sensor nodes interacting with the physical world, hence having potential applications in traffic surveillance systems. It presents several appealing features. First, the simplicity of setup makes it suitable for virtually any environment. Second, since no fixed infrastructure is required, this technology is cost effective compared to the existing monitoring tools. Moreover, the wireless sensors are self-organized to establish networks via wireless communication modules installed in the nodes, they are small and cheap with high flexibility regarding the change of the existing topology. Finally, WSNs can be densely deployed and usually constituted of a large number of nodes, which provides better coverage of the road networks infrastructure and ensure more accurate traffic management decisions.

The aim of our work is to investigate the efficiency of WSNs for traffic monitoring [6] in road environment and reduce data transmission latency to insure better support of real time data collection with medium access fairness. To achieve this goal, we need first to design an adequate medium access protocol that fulfills the requirements of WSNs along with the ITS applications demands in terms of transmission delay. To this end, many researchers have focused their efforts on designing such MAC protocol, dubbed IEEE 802.15.4 [3], which is commonly used for inter-sensors communication. In this paper, we propose a novel backoff computation mechanism in order speed up channel access for sensors reporting incidents.

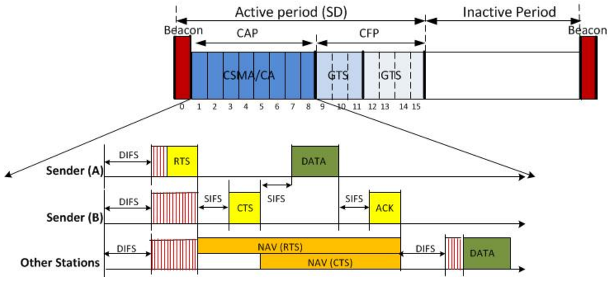

Figure 1: Illustration of the IEEE802.15.4 super frame structure and CSMA/CA scheme

The remainder of this paper is structured as follows. We first give an overview of IEEE802.15.4 in Section II. After that, we present the related contributions for the MAC protocols in WSNs and highlight their limitations in Section III. In section IV, we present our scheme in details and evaluate its effectiveness in section V. Finally, we conclude the paper and discuss the future work in Section VI.

II. OVERVIEW OF IEEE802.15.4

IEEE 802.15.4 [3] is an emerging technology designed to address the need for low-rate, low-power and low-cost wireless networking, based on Carrier Sense Multiple Access-Collision Avoidance (CSMA-CA) [7] which generally has the advantage of offering a low delay and high throughput [4]. Access to the medium is based on combination of random access and scheduled access. The MAC is controlled by the Personal Area Network (PAN) coordinator that may choose to operate on beacon enabled access mode or beacon-less access mode.

The beacon mode begins with the beacon frame sent periodically to synchronize the attached devices. The beacon contains information about the coordinator and super-frame structure which is defined as the period between two consecutive beacons. The super-frame structure is divided into 16 slots. The first slot is occupied by the beacon, other slots used for data communication by mean of random access, and from the so-called Contention Access Period (CAP). The PAN coordinator can reserve more than one slot. These slots are referred to as Guaranteed Time Slots (GTS), and they form the Contention Free Period (CFP) of the super-frame [7]. In non-beacon-enabled mode, a PAN coordinator does not use any synchronization. Since there is no super-frame, no GTS can be reserved and random access phase devices adopt CSMA-CA.

The CSMA-CA scheme used in IEEE802.15.4 standard can be summarized as follows: when a device needs to send data it draws a random backoff delay from a Contention Window (CW) interval. When the backoff delay expires, the device performs a Clear Channel Assessment (CCA) operation, consisting in listening to the channel in order to determine if it is idle. If the channel is idle the device immediately transmits the data packet; otherwise, it repeats the procedure by picking a new backoff delay.

III. RELATED WORK

MAC layer plays a key role for QoS provisioning and dominates the performance of the QoS support. The MAC layer controls how sensor nodes share communication resources and establish communication links for data transfer purposes. An efficient MAC protocol increases the lifetime of a WSNs since it is impractical to change or replace the battery of sensors. Designing an energy efficient MAC protocol for WSNs presents a common objective of several works in the literature, as described below; however transmission delay reduction has received little attention from the community. Therefore, we will present in this work a delay efficient MAC protocol for WSNs in road environment.

The most important work is the Sensor-MAC (S-MAC) [10] protocol which is characterized by two periodic modes: sleep and wake up. The idea behind this protocol is to reduce the communication power consumption and let the nodes simultaneously wake up and fall back to sleep. The S-MAC protocol is synchronized through the SYNC packets, using preamble-sampling technique[14]. Each cluster has an independent schedule composed of three periods: SYNC, DATA, and SLEEP. The nodes in the same cluster wake up at the beginning of the SYNC period to synchronize the clocks with each other. This represents a problem of twice the duty cycle to the bordering nodes in-between two clusters. Nodes that are not involved in communication return to sleep at the start of the SLEEP period. Another important issue is the fixed length of the duty cycle, which severely restrains latency in the case of burst traffic and variable traffic loads [8]. Moreover, the multiple on/sleep schedules on the edge nodes may result in unbalanced energy cost and losing communication coverage.

Other protocols have modified the S-MAC protocol such as Time-out MAC (T-MAC) [9]. In this latter, the length of the active period is not fixed as in S-MAC. The listening interval in T-MAC ends when the node detects any communication on the radio. This design aims to achieve optimal active periods under various traffic loads. The drawback of T-MACs adaptive time-out policy is that nodes often go to sleep too early which leads to an important delay in real time data collection. A recent survey [15] has explored the most significant contributions dealing with the energy efficiency issue such as, a Different Service MAC (DSMAC) [11] that extends S-MAC by adding a dynamic duty cycle feature. Another interesting proposal reviewed in this survey is the Traffic Adaptive MAC (TA-MAC) [13] which adapts the CW to the current traffic load, instead of using a constant CW as in S-MAC.

Most of the works focus on the energy efficiency because the sensor nodes are usually limited in their power supply resources. Recently, research attention turned back to throughput, delay and efficient delivery of busty traffic. The authors of [18] have proposed a new MAC protocol that reduces the end-to-end transmission latency through controlling the transmission power in multi-hop WSNs. To achieve their goal, they reduce the transmission range of the nodes by transmitting packets with minimum sufficient power level to reach the next

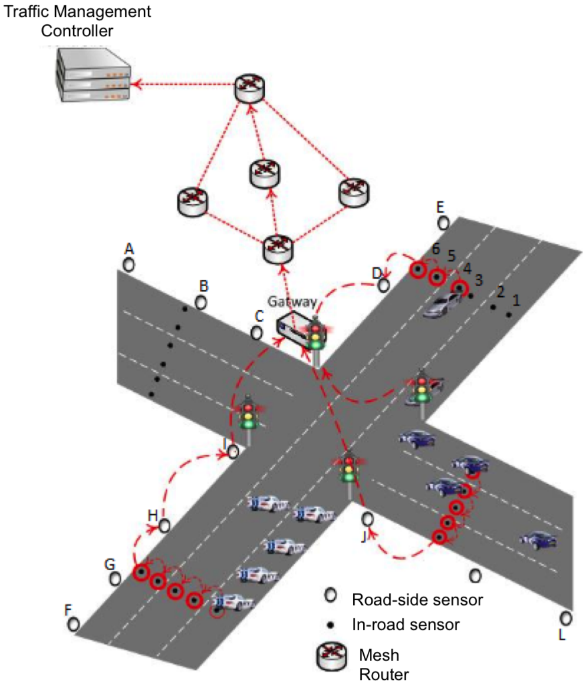

Figure 2: Scenario illustrating WSN deployed in road environment for traffic monitoring purposes (the deployed equipments include Road-side sensors, Gateway, Mesh routers and TMC)

hop, hence other nodes in the sender's Career Sensing Range (CS_R) can receive/transmit data simultaneously without interfering with the ongoing transmission. However, in such scheme, the number of hops separating the sender node and its destination increases significantly, which may lead to slight or no decrease at all of the end-to-end delay. Furthermore, in dense WSNs, collisions still occur even when reducing transmission power, which makes this scheme inefficient.

In addition to this work, a protocol named Latency Energy MAC Routing (LEMR) [16] has been proposed for WSNs applications with low energy, low latency and high reliability. Its main idea is shifting the channel-polling interval according to the distance of the node to the sink in number of hops. LEMR uses a coordinator node whose role is the most important in the network, as it is responsible for sending the synchronisation messages that contain information about time of the next channel polling. However this protocol is not suitable for road traffic monitoring since the mechanism of channel polling is inefficient in the case of random events detection like in emergency situations.

Many TDMA (Time Division Multiplexing Access) based MAC protocols have been proposed in WSNs. The most important protocol is the PEDAMACS [17] which applies a scheduling algorithm that ensures that packets reach the sink at the end of each scheduling phase. The synchronisation overhead is one of its major drawbacks, in addition to its restriction to one hop transmission only. Therefore, this makes it unsuitable for multi-hop and emergency data transmission.

IV. THE PROPOSED SOLUTION

In this section, we present the architecture used in our work and the designed MAC protocol for WSNs.

A. *Architecture overview*

Our architecture comprises of one gateway that collects traffic data reports from a large number of sensors deployed in the roadside, as shown in Figure 2. We distinguish two different configurations of the road-side sensors; the first set of sensors (A, B, C, D ...) forms linear topology where static nodes are arranged in parallel. In this configuration, we assume that these sensors are equipped with permanent energy supply, thus the problem of energy consumption is neglected. On the other hand, other sensors are deployed transversely (1, 2, 3, 4 ...), one per lane across the road in order to collect and report data traffic information such as: the number of passing vehicles, their speed, incidents and weather conditions.

In our architecture, the WSN gateway is deployed in one corner of the road intersection. The gateway has an important role in the synchronization of the sensor nodes. It is also used for priority management of the different packets through the use of three types of queues with different priority levels: high, medium and low level according to the importance of the messages as described in next subsection. We connect the gateway to the local Traffic Management Controller (TMC) via Wireless Mesh Routers constituting a Wireless Mesh Network (WMN). The role of WMN is to provide a flexible road-side relay between WSNs and the TMC rather than using the currently deployed infrastructure which is costly to maintain and change.

B. *Class of messages*

In our architecture, the sensors are deployed to measure and report three types of data classified into three different categories according to their content type (i.e. the emergency level of the content), as follows.

- Weather conditions: data representing temperature, pressure and humidity etc. These parameters are measured periodically and sent only if the sensed data are different from the last sent values. To this end, we keep track of the last sent data and use it as a threshold. This type of data represents the lowest priority class (i.e. they are less critical for TMSs efficiency).
- Traffic conditions: the data collected by this type of sensors are vehicles speed, flow speed and volume.... These sensors should be always in active mode in order to transmit the sensed data. This class of sensors has higher transmission priority than the previous class.
- Incident report: this report is triggered by an accident, a stalled car in the road or any other incident reported by the sensors mounted in the passing cars. Such events are detected when the sensors measure a zero speed, or the road-side sensors receive an alarm from the on-board sensors. This type of data requires very short transmission time and has the highest level of priority at the gateway queue.

The main goal of our work is to reduce the transmission delay of the messages belonging the third class described above. To this end, we design the backoff selection scheme described in the following.

C. New MAC protocol for low delay transmission

Since we have to transmit different types of data with different levels of priority, the challenge in this case is to speed up the channel access for a sensor reporting a detected incident. To face this challenge, we propose to adapt the CW to the class of the message to be transmitted as explained, in details, in the following sub-sections.

*1) **Priority based messages classification**:* we propose to adapt the CW in CSMA/CA according to the class of each message, as proposed in [12]. However, we use a novel adaptation approach in our solution. In this solution, we integrate medium and low level priority messages (see Section IV-B) in Class 2 and messages reporting incidents in Class 1. As a result, a class index $C \in \{1, 2\}$ is attached to each packet. These two classes are defined as follows:

- Class 1: it corresponds to incident reporting and requires a minimum transmission delay from the detector node to the sink. This class requires a small backoff value for fast access to the medium.
- Class 2: it corresponds to weather and traffic conditions. The transmission of this data is periodic and has no guarantee required (Best effort).

*2) **CW adaptation**:* to achieve our goal, the backoff values are computed according to Normal or Uniform distribution based on the class index C of the packet to be transmitted, as shown in Figure 3. Let us assume that X is a random variable that represents the backoff delay and its value varies within the interval $[0, CW]$, hence X can be defined as follows:

$$X|C = 1 \sim N(\mu, \sigma^2) \tag{1}$$

$$X|C = 2 \sim U([CW/2, CW]) \tag{2}$$

where:

- N: Normal distribution
- U: Uniform distribution
- μ: Mean of the Normal distribution N initialized with $\mu_0 = CW/4$
- σ^2: Variance of the Normal distribution N, such that $\sigma = CW/4$. Note that we set a fixed value of σ to allow many values of the backoff to be chosen.

On one hand, we use a normal distribution with a small mean to draw the backoff values for the emergency messages (i.e. Class 1), in order to increase the probability to pick ”small” values. More precisely, we use a truncated normal distribution such that the backoff cannot be negative nor exceed a certain threshold set as: $\mu + \sigma$.

On the other hand, we use a uniform distribution on the segment [CW/2, CW] to draw the backoff values for the periodic messages (i.e. Class 2). This scheme grants lower backoff values for emergency messages, hence ensuring a lower delay. The mean of the normal distribution is updated with the Algorithm 1.

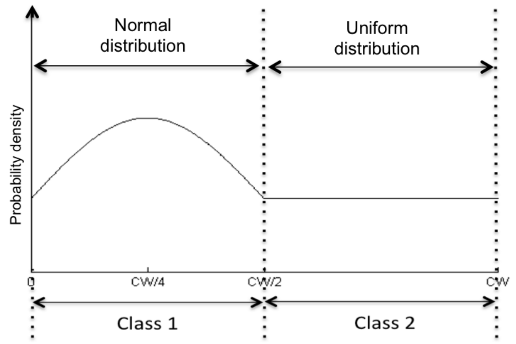

Figure 3: The backoff distribution used in our scheme

Our proposal consists in fixing a smaller mean in order to get a small backoff according to the standard deviation. This distribution allows the node to pick a backoff around the mean with high probability. We set the standard deviation in our implementation and propose the algorithm 1 to compute the mean value accordingly.

We assume the following delay threshold D_{th} defined as the maximum allowed delay per node for the transmission of emergency messages. This threshold represents the delay of successful transmission plus error tolerance value ε.

$$D_{th} = D_{SuccTr} + \varepsilon \tag{3}$$

$$\begin{aligned} D_{SuccTr} &= T_{DIFS} + T_{Backoff} + T_{RTS} + T_{SIFS} + T_{CTS} + A \\ A &= T_{SIFS} + T_{Data} + T_{ACK} \end{aligned} \tag{4}$$

such that:

- T_{DIFS}: DCF Inter-Frame Space, time to wait before the sensor node starts counting down its backoff value.
- T_{SIFS}: Short Inter-Frame Space, time required for a sensor node to switch its transceiver from the reception state to the transmission state.
- T_{RTS}: the estimated time to transmit a Request To Send frame
- T_{CTS}: the estimated time to transmit a Clear To Send frame
- T_{Data}: the estimated time to transmit a Data frame
- T_{ACK}: the estimated time to transmit an ACK frame
- ε: refers to error tolerance value for the successful transmission

For the $i-th$ event, the node computes the expected transmission delay for the emergency message that advertises the detected event. This delay is called the measured delay d_i. We define two states of the channel: idle and busy. The measured delay when the channel is idle (d_i^I) is the delay of successful transmission (D_{SuccTr}) plus this delay multiplied by the Probability of Collision (P_c) [19] [1], and the Maximum Number of allowed Retransmission (N_{RT}), as shown in Equation 5.

$$d_i^I = D_{SuccTr} \times (1 + P_c \times N_{RT}) + \varepsilon \tag{5}$$

where

$$P_c = 1 - (1 - 1/W_{avg})^{m-1} \tag{6}$$

such that W_{avg} refers to the overall average backoff window.

When the channel is busy, d_i^B is defined as the sum of d_i^I and the remaining NAV duration (T_{NAV}) as shown in the following Equation.

$$d_i^B = d_i^I + T_{NAV} \tag{7}$$

The measured delay d_i is aggregated according to the Equation 8. This equation aims to reduce the probability of error by adding the previous aggregated delay with a low weight θ. We choose a small value of θ, so as the measured delay will be privileged compared to the previous delay.

$$D_i^{B/I} = (1 - \theta) \times d_i^{B/I} + \theta \times D_{i-1}^{B/I} \tag{8}$$

where $D_{i-1}^{B/I}$ refers to the previous aggregated delay and θ varies from 0 to 1. Notice that B/I stands for "Busy" or "Idle".

*3) **CW adaptation algorithm**:* once the delay is computed and aggregated, we compare $D_i^{B/I}$ with D_{th} computed at the beginning. If $D_i^{B/I}$ is smaller than D_{th} we keep our previous mean, otherwise we decrement the mean so that a smaller backoff will be chosen in the subsequent iteration.

The proposed algorithm allows prioritizing the emergency messages by dividing the CW's interval. The operations of our algorithm are summarized in Algorithm 1 which can be split into the following steps.

1) Initialization of the different variables
2) Computation of the delay for both idle and busy states as well as the threshold value.
3) In the next step we compare the measured delay d_i^I with the delay threshold D_{th}. If the condition is held we keep the previous mean, and divide the CW interval according to the class of messages. In this way, we pick a backoff for the emergency events around the mean. In order to avoid that the periodic messages select a small backoff we shift the CW interval of the class 2 from $[0, CW]$ to $[\mu_{i+1} + \sigma, CW]$.
4) If the condition is not verified, we decrease the value of the mean by 1 and compare it with the threshold μ_{th}. If the resulted value is smaller or equal to this threshold then we rest it to the inial mean value μ_o.

Notice that our algorithm allows the emergency events to be advertised to the TMC within the required delay.

Algorithm 1 MAC Algorithm for Contention Window Adaptation

```
 1: $\mu_0 \leftarrow CW/4$; $\mu_{th} \leftarrow CW/8$, $i \leftarrow 0$
 2: Compute $D_{th}$ with equation 3
 3: if Channel is Idle then
 4:     Compute $d_i^I$ with equation 5
 5:     Compute $D_i^{B/I}$ with equation 8
 6:     if ($D_i^{I/B} \leq D_{th}$) then
 7:         $\mu_{i+1} = \mu_i$
 8:     else
 9:         $\mu_{i+1} = \mu_i - 1$
10:         if $\mu_{i+1} \leq \mu_{th}$ then
11:             $\mu_{i+1} = \mu_0$
12:         end if
13:     end if
14:     $CW_{c1} = [0, \mu_{i+1} + \sigma]$
15:     $CW_{c2} = [\mu_{i+1} + \sigma, CW]$
16: else
17:     Channel is Busy
18:     Compute $d_i^B$ with equation 7
19:     go to step (5)
20: end if
```

Table I: Summary of simulation parameters

Parameters	Value
Transmission range	80 m
Traffic type	CBR
Routing Protocol	AODV
Propagation model	TwoRayGround
Total number of sensors	13, 20, 30, 50
Size of emergency messages	80 Bytes
Size of periodic messages	75 Bytes
Data rate	250 KBS
Simulation time	200 seconds
No. of simulation epochs	5

V. PERFORMANCE EVALUATION

In this section, we present the simulation topology, parameters setting and discuss the obtained results. To implement our scheme, we have modified the existing implementation of IEEE802.15.4 protocol in ns-2.35 network simulator [20] by adding new functions to the file 802.15.4csmaca.cc. The main metric to be evaluated in this simulation is the end-to-end transmission delay of the emergency messages reporting incidents. We have deployed the same topology depicted in Figure 2 with varying number of sensors and the inter-packets transmission interval. The messages reporting both periodic and emergency events are sent to the sink node through multi-hop transmission. In our simulation, we generate two types of traffic: one sent periodically (based on CBR traffic) to report the number and speed of the passing vehicles; at the same time we generate a random traffic that reports the incidents that may occur randomly during simulation time. Simulation parameters and configuration are summarized in the Table I.

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[1] Notice that we used the same collision probability formula as in IEEE802.11 because IEEE802.15.4 applies CSMA/CA during the CAP period

The histogram plotted in Figure 4 compares the average end-to-end delay of all messages transmitted towards the sink node regardless of their type, under various values of periodic messages transmission interval. In this simulation scenario, we set a WSN of 20 nodes with 5 sources of traffic (three sources for periodic messages and two for random messages). We run our simulation with the standard IEEE802.15.4 and our scheme without distinction between the two types of messages. We can clearly observe from this histogram that our scheme achieves a lower end-to-end transmission delay compared to the standard protocol. The achieved improvement here is almost 21% in case of transmission interval of 5 and 10 seconds, and increases to around 50% when this interval gets larger (i.e. equal to 30 and 60 seconds).

Figures 5(a) and 5(b) show the average end-to-end delay under varying transmission intervals of periodic messages. In this scenario, we run our simulation under the same parameters applied in the previous scenario; however we have applied our scheme with strict distinction between periodic and emergency messages (i.e. the Backoff values of each of them is calculated differently according to the Algorithm 1). The results graphed in Figure 5(b) reveals that our scheme achieves a shorter average end-to-end delay compared to IEEE 802.15.4 in case of emergency messages. On the other hand, a shorter delay is also ensured for periodic messages, as shown in Figure 5(a), even though the improvement here is less significant than that achieved for emergency messages transmission. As periodic messages are usually carrying information that doesn'tt require strict delay constraints, the achieved delay will not affect the efficiency of the TMS.

We notice also in the previous results, that the end-to-end delay is inversely proportional to the value of inter-packets transmission interval. This is due to the fact that a small value of this interval leads to a considerable increase of the traffic load in the WSN, which consequently increases the end-to-end delay for both types of traffic. Since the backoff value is chosen randomly in the standard IEEE 802.15.4 without any priority for the emergency messages, the histograms in Figures 5(a) and 5(b) highlight that the delay of emergency message can be higher than that of periodic messages, in some cases. For example, when the transmission interval is equal to 5 seconds the end-to-end delay of emergency messages is equal 18.94 seconds (see Figure 5(b) the black bar), whereas the delay is equal to 17.66 seconds for the periodic messages (see Figure 5(a) the dark blue bar).

Figures 6(a) and 6(b) show the impact of the size of the network on the average end-to-end transmission delay for both periodic and emergency messages. In this scenario, the number of hops separating the sender sensor to the sink increases with the increase of the WSN size. Moreover, we have used different values of seed to make our results more significant. The results depicted in these figures show that the end-to-end delay increases with the increase of the WSN size. Despite this increase, our scheme is able to deliver the emergency messages to the sink faster than the standard IEEE802.15.4, at the expense of a slight increase of the periodic messages delay, in some cases such as when the WSN size is equal to 13 (see Figure 6(a)the red bar). Notice here that the delay reduction of emergency messages is very important as their early reception at the sink, then by the TMC will allow faster reaction to the advertised danger on the road.

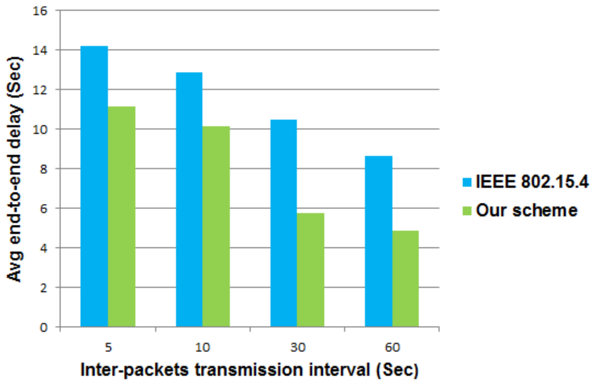

Figure 4: Average end-to-end delay of all messages: under varying inter-packets transmission interval

To conclude, we can say that these results prove the efficiency of our scheme. This latter has achieved significant improvement of emergency messages delivery delay while kept almost the same periodic messages delivery delay as that achieved by the standard IEEE802.15.4.

VI. CONCLUSION

We have proposed in this paper a new adaptive backoff scheme for IEEE802.15.4 protocol in order to ensure faster transmission of emergency messages in road environment. The main idea of our proposal is to adapt the backoff selection interval to the class of message being transmitted based on a Normal distribution. Using this adaptation, the messages reporting incidents or dangerous events are granted a smaller backoff compared to those carrying periodic traffic flow or weather information. The performance evaluation results highlight the effectiveness of our scheme under varying WSNs sizes and periodic messages transmission frequencies. As a future work, we plan to design data aggregation technique for inter-sensors transmission and combine it with our scheme to achieve better delay improvement.

VII. ACKNOWLEDGEMENT

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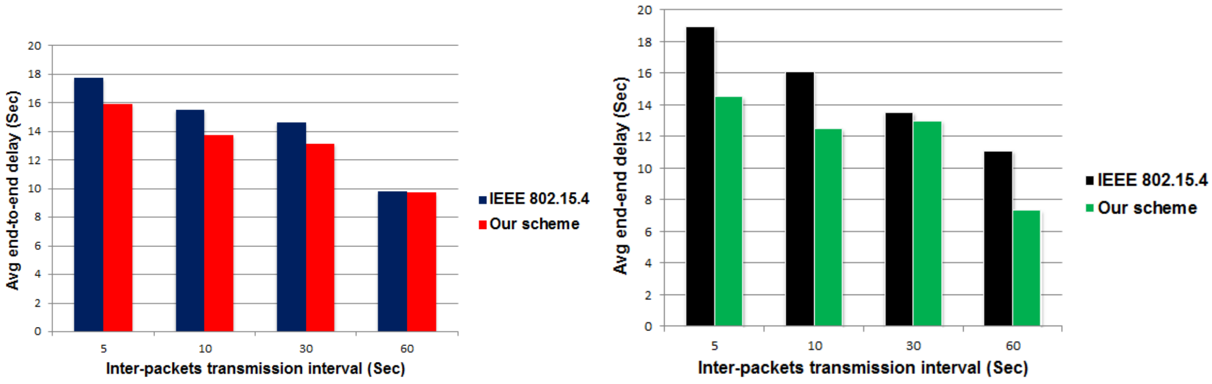
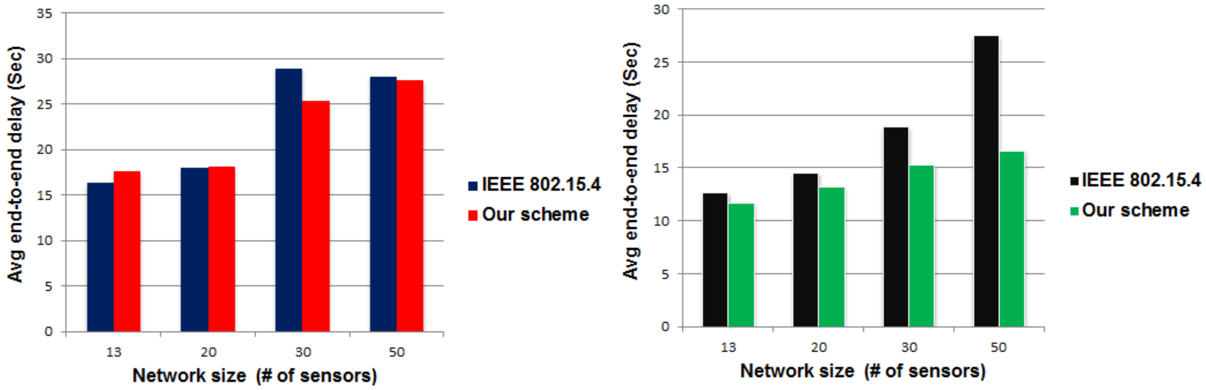


(a) Periodic messages end-to-end delay

(b) Emergency messages end-to-end delay

Figure 5: Impact of inter-packets transmission interval of periodic messages on Average end-to-end delay: our scheme vs. IEEE802.15.4



(a) Periodic messages end-to-end delay

(b) Emergency messages end-to-end delay

Figure 6: Impact of number of hops separating the detector sensor from the sink on Average end-to-end delay: our scheme vs. IEEE802.15.4

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