Development of an intelligent electronic sentinel for the monitoring and detection of meteorological phenomena due to global climate change

Sadouni Salheddine
Electronics Department
University of Constantine 1
Constantine, Algeria
salaheddinesadouni@umc.edu.dz

Sadouni Ouissal
Software Technologies and Information Systems Department
University of Constantine 2
Constantine, Algeria
ouissal.sadouni@univ-constantine2.dz

Benslama Malek
Electronics Department
University of Constantine 1
Constantine, Algeria
ma_benslama@yahoo.fr

Messai Abderraouf
Electronics Department
University of Constantine 1
Constantine, Algeria
r_messai@yahoo.fr

Beylot André-luc
Institut de Recherche en Informatique de Toulouse
University of Toulouse
Toulouse, France
andre-luc.beylot@enseeiht.fr

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***Abstract*—In the last few years we have been witnessing with stupefaction the intensification of the majority of meteorological phenomena as a direct consequence of the global warming of the planet. The latter, occupies a preponderant place in scientific research, to define with precision its present and future repercussions on human life. For this purpose, a continuous and real-time monitoring of the physical quantities characterizing meteorological phenomena is necessary for their good understanding as well as their early detection and the triggering of alarms during emergency situations. Therefore, in this paper we focus on the development of an intelligent electronic sentinel, which will be able to collect, process environmental data to detect those meteorological phenomena that form in its direct vicinity. In this respect, our electronic sentinel will rely on artificial intelligence to enrich these knowledge bases and ensure the veracity of the phenomena it quantifies by avoiding triggering false alarms.**

Keywords—Electronic sentinels, Artificial intelligence, Global warming, Meteorological phenomena, Detection, Real-time monitoring

I. Introduction

Nowadays climate change, and more specifically global warming, has become a reality that no one can deny. Resulting from atmospheric modification, global warming is caused by greenhouse gas emissions ; mainly generated by human activities. Thus, global warming leads to the aggravation of several meteorological phenomena (drought, floods, forest fires, etc.) which renders it very common in various fields of research and a challenge for today's and tomorrow's societies [1]. To properly identify and manage these weather phenomena, it is essential to measure them over large geographical areas, covering small-scale cities, regions, countries or even continents on a large scale. One of the possible solutions to this problem is the use of new electronic entities for the detection and real-time monitoring of these weather phenomena. These entities must include different types of sensors, in order to measure several physical quantities related to the triggering of these phenomena (temperature, air and soil moisture, atmospheric pressure, pollution, etc.), these entities are called electronic sentinels[2].However, these electronic sentinels must take into account the nature of the phenomenon to be monitored and the context under consideration, with the aim of providing a digital model that is faithful to the physical environment covered by these sentinels. In addition, the electronic sentinels must be equipped with some form of intelligence to ensure the collection and processing of periodic and sporadic environmental data, in order to report abnormal situations. To do so, we will integrate new artificial intelligence algorithms that can provide an appropriate response to the situations encountered. In this paper, we propose the development of an intelligent electronic sentinel for the monitoring and detection of meteorological phenomena resulting from climate change [1].

For this purpose, our paper will be organized into several sections. In the first section we will focus on the electronic sentinels, their goals, tasks and functioning. The second section will be devoted to the design and architecture of our sentinel as well as the presentation of its different modules. We will devote the third section of this paper, to the prototyping of our electronic sentinel by exposing its design and its hardware and software implementation. We will then present the meteorological phenomena targeted by our sentinel in section four. The fifth section of this paper will be dedicated to the simulation and its parameters as well as the results obtained. Finally, we conclude our research work in section six with a conclusion and several suggestions for future works.

II. Electronic Sentinels

The main goal of the development of these electronic sentinels is to provide an optimal method of detecting meteorological phenomena and monitoring the environment in real time. Indeed, an electronic sentinel will be able to collect and process a periodic traffic of data from its direct environment of action such as air quality, temperature, humidity or from a remote environment through an extension of this same sentinel in the form of a collection of remote sensors such as soil moisture, the level of rainwater, the level of nitrogen in the soil, etc. On the other hand, the electronic sentinel carries out sporadic data processing in order to detect emergency situations such as forest fires, floods or even the alarming increase in air pollution [2]. These emergency situations will be followed automatically by the triggering of the appropriate behaviour : notifying an alarm to the service concerned, sending the location of the phenomenon, collecting large amounts of data to better record the meteorological phenomenon and to make it easier to apprehend it next time. Such behaviour requires the implementation of two different phases : a training phase followed by a test phase. This leads us to exploit the concepts of artificial intelligence during the process of data processing within our electronic sentinel [3]. Furthermore, our electronic sentry must operate in isolated places far from any energy source, which implies the use of a power module (solar panel, batteries, charge regulator) and another one for long-range communications. We will discuss all these elements in the rest of our paper. In order to better quantify certain meteorological phenomena and to avoid being misled, we collect environmental data from various physical environments ; for example, measurements of air and soil moisture or air and soil temperature [1]. This involves the separation of our electronic sentinel into two distinct parts :

A. The super-sentinel or the parent sentinel

Has a greater autonomy and considerable material resources to ensure its functioning as well as the functioning of the sub-sentinel (child sentinel). It also ensures the processing of data (collected by itself and its child), the detection of emergency situations and the decision making for the triggering of the appropriate behaviour for each one.

B. Sub-sentinel or the child sentinel

Under the continuous control of the parent sentinel, it is considered as an extension of the latter. The child sentinel will only collect data and send it to the mother sentinel as requested.

III. Design And Architecture Of An Electronic Sentinel

As mentioned above, the design of our electronic sentinel uses several modules: a processing module, a sensing module, a Transceiver module and a power supply module.

A. Processing module

This module represents the main unit of our electronic sentinel, it consists of a microprocessor coupled to a random access memory and a storage unit (a hard disk) in which a mini-operating system is installed. In parallel with the control and proper functioning of the other modules of the electronic sentry, the processing module, as its name indicates, ensures the processing of data collected from local and remote sensors. In addition, it takes care of detecting emergency situations by triggering the appropriate behaviour for each one. To do so, the machine learning algorithm will be pre-installed on the storage unit, to be assembled with our sentinel's operating system [4].

B. Sensing module

Mainly made up of local sensors (integrated in the parent sentinel) and remote sensors (in the child sentinel), these sensors allow us to collect physical quantities directly related to the meteorological phenomenon that we want to quantify. The sensors that we will use for the implementation of our electronic sentinel are air and soil moisture, temperature, barometric pressure, carbon monoxide, rain sensor and water level [4].

C. Transceiver module

This module handles in one hand the transfer of data and command packets between the daughter and mother sentinels and on the other hand sends data and alarms to a remote server. For communication between the mother and daughter sentinels, Bluetooth is the technology that has been chosen, as the distance between the two sentinels does not exceed ten meters. For the communication between the parent sentinel and the remote server, we have chosen 4G mobile phone technology. It provides very long-distance links with high data throughput. For long-distance links, there are other technologies (Sigfox and LoRa) that we can retain in future work, low in speed and energy consumption but ideal for IOT (internet of things) applications. A 4G network uses the 1800 MHz frequency band, which is congested in some areas, causing interruptions in traffic at certain times. Therefore, we recommend to develop in future works, an evolutive architecture of our electronic sentinel ; which will be able to communicate through a 5G network. The latter offers low latency access, high reliability and increased throughput compared to 4G networks [5].

D. Power supply module

An important part of our sentinel's architecture, as it takes care of the energy supply for all the other modules. As far as we are concerned, our sentinel can be used for surveillance operations in isolated areas where no energy source is available. So we opted for the use of a solar panel linked to a battery and a voltage regulator. The latter uses solar energy to power all the modules of the sentinel and recharges the battery in the presence of solar energy or, in its absence, switches the power supply of the sentinel directly to the battery. In addition, our electronic sentinel must be equipped with a GPS beacon in order to signal its exact position when an alarm is triggered. We also point out that this device is expensive in terms of energy consumption [4]. This leads us to trigger it manually when the sentinel is launched, until the position is stored in the processing module and the device is switched off, since its mobility is very limited or virtually non-existent (Fig. 1).

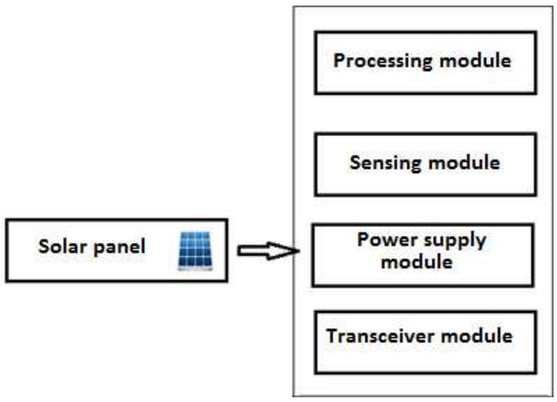

Fig. 1. General architecture of an electronic sentinel

IV. The Prototyping Of Our Electronic Sentinel

In order to put into practice all the elements we have discussed in the previous sections, we need to make a prototype of our electronic sentinel (parent) and its extension (child). To do so, we will divide our work into several stages :

- Specification of the required electronic components.
- Computer-aided hardware design.
- Hardware implementation of our electronic sentinel.
- Software design and implementation of our electronic sentinel.

A. *Specification of the required electronic components*

In order to carry out the tasks of our electronic sentinel we will be using the following electronic components in table I :

TABLE I. ELECTRONIC COMPONENTS OF OUR SENTINEL.

	Electronic components	**Features**
1	DHT 22	Air Humidity and Temperature Sensor
2	MQ2	Gas and smoke detector sensor (300 ppm to 10000 ppm)
3	MQ9	Sensor for detecting carbon monoxide and flammable gases
4	MQ135	Sensor for measuring CO_2 air quality
5	BMP180	Barometric pressure sensor
6	ST045	Water level sensor
7	Raindrops	Rain Sensor
8	ARCELI 5PCS	Soil moisture sensor
9	Arduino Mega	Programmable electronic card for parent sentinel
10	Arduino UNO	Programmable electronic card for child sentinel
11	Bluetooth	Parent / child sentinel interconnection medium
12	SIM7600CE-T 4G(LTE)	Parent sentinel / remote server interconnection medium
13	NEO-6M GPS module	Our sentinel's GPS locator beacon
14	Solar panel + battery + load regulator	Ensures the supply of our sentinel's components

B. *Computer-aided hardware design*

The computer aided design in the electronic field is an unavoidable step in the process of realizing electronic projects such as the ours. Indeed, this design allows us to virtually prototype our electronic sentinel while reducing hardware and software costs. As a result of this step we will have the electronic assembly diagrams of each component and then we assemble them to have the final electronic diagram of our sentinel [2]. In this paper we will focus on the final electronic assembly diagram of the parent and child sentinels, as shown in the following Fig. 2 and 3 :

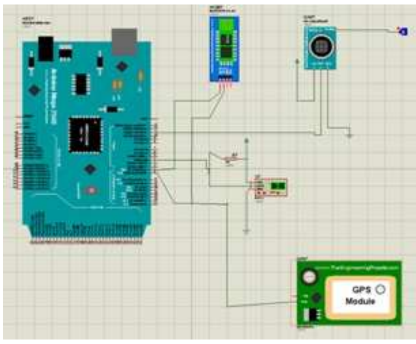

Fig. 2. The final assembly diagram of the parent sentinel

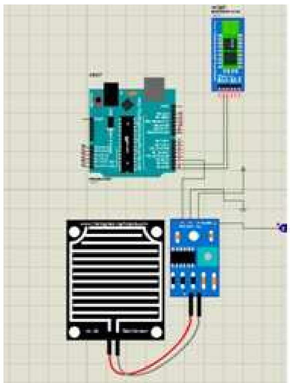
Fig. 3. The final assembly diagram of the child sentinel

C. *Hardware implementation of our electronic sentinel*

Based on the final assembly diagram of our electronic sentinel (parent and child) discussed in the previous step, as well as the technical characteristics of each electronic component, we proceed to the connection of the latter [6]. For reasons of patenting of our prototype we will show only parts of the assemblies (Fig. 4 and 5).

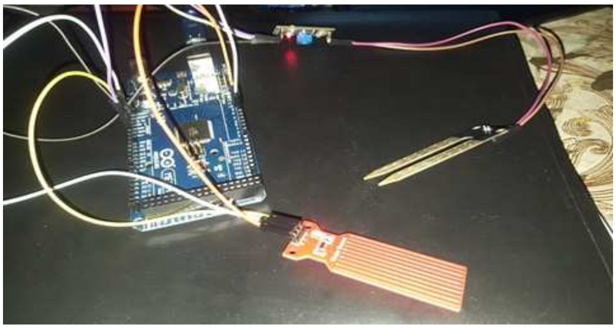
Fig. 4. Part of the child sentinel's connection

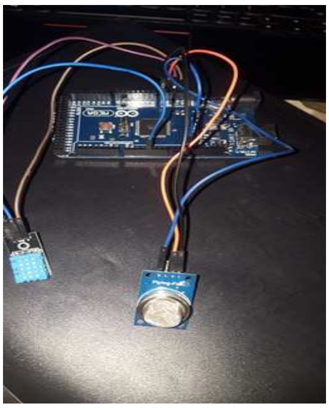
Fig. 5. Part of the parent sentinel connection

D. *Software design and implementation of our electronic sentinel*

The aim of our system is to detect forest fires or floods based on the data collected by the electronic parent and child sentinels. Indeed, the data collected by the latter are stored periodically in the hard disk of the sentinel and simultaneously sent to the remote server. These data are then used by our program which is based on artificial intelligence to indicate the presence of a phenomenon or not. In case of detection of one of the above mentioned phenomena the system sends the current data to the remote server allowing a real time monitoring. The core of our system is based on a machine learning algorithm known in the field of artificial intelligence known as the naive Bayes classifier [7].

It is a classification algorithm that allows to build a decision rule in order to predict the right classification from the input parameters. Its mechanism is divided into two phases, a training phase which consists of using the supervised data to build up rules that can provide a judgement close to that of the reality (the right class).

A supervised data is a data that has been labeled by an expert in the field, in our case starting from a time series containing the values of the sensors used, a geographer assigns a label / class "flood" or "forest fire" or "normal" to his data according to the general cases.

The second phase is the test phase, as its name indicates it involves testing the model built from the rules elaborated in the previous phase, to check whether the built model is reliable or not. Indeed, the Bayes algorithm has already proven its results in the detection of anomalies [8] thanks to its great capacity of not being swayed by the noise (outliers) which is the main reason for which we have chosen it among the range of existing algorithms.

Noises are data modified by several factors, and which do not allow the algorithm to build efficient rules. Among these factors are the sensors themselves [7]. Based on Bayes' theorem, the algorithm provides the correct "A" label to a "B" input :

$$P(A|B) = \frac{P(A)\,P(B|A)}{P(B)} \quad (1)$$

In the following to help explain the algorithm, the term phenomenon expresses a class that represents the presence of a phenomenon (forest fire/flood) or nothing :P(A) is the frequency of the phenomenon A in the dataset; P(B|A) the probability of finding a parameter B (e.g. soil moisture <10%) in phenomenon A (e.g. forest fire); P(B) the probability of B independently of the phenomenon, e.g. the probability of observing an air temperature = 40C°; P(A|B) the probability of A being the correct phenomenon to which one should assign observation B, for example the probability that "flooding" is the correct phenomenon to predict when the volume of water = 0.70 cm^3.

The theorem is then simplified based on the assumption that the data follow a normal distribution, resulting in (2):

$$P(B|A) = \frac{1}{(2\pi)^{\frac{p}{2}} det\,(\Lambda_A)^{\frac{1}{2}}} exp\left(-\frac{1}{2}(B - \overline{B_A})^T \Lambda_A^{-1}(B - \overline{B_A})\right) \quad (2)$$

det Λ_A is the determinant of the variance covariance matrix of the phenomenon A; $\overline{B_A}$ is the mean of parameter B in phenomenon A

Algorithm 1: Naive Bayes Classifier Algorithm for Detecting Meteorological Phenomena

Input : data collected by all the sensors used, and labelled by an expert in the field to form a dataset D

Output: the prediction of the phenomenon: "flood", "forest fire" or "normal"...

1. **Foreach** : phenomenon A belonging to the dataset D
2. Calculate the average of A
3. Calculate the variance-covariance matrix of A
4. Calculate P(A)
5. Calculate P(B|A) using formula (2)
6. Put P(B|A) in a vector
7. **EndForeach**
8. Sort the final vector
9. **Return** the phenomenon p with the largest P(B|A)

Then from the results obtained from the the algorithm, the program decides to send an alert or not to the remote server, according to the following architecture in Fig. 6 :

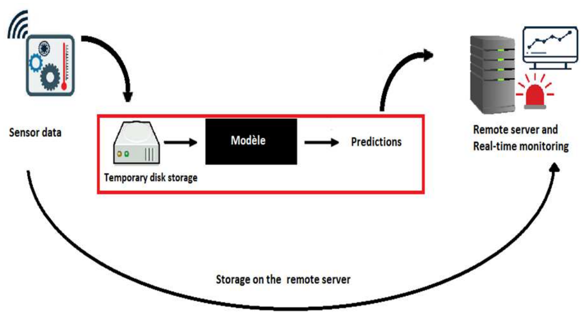

Fig. 6. Architecture of the Meteorological Phenomena Prediction System

We use two metrics to evaluate the results of our algorithm : Accuracy represents the percentage of correct predictions compared to all predictions made, calculated using (3) :

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN} \quad (3)$$

Such as : true Positives (TP) refer to the cases where the actual phenomenon of the input to be classified = true and the prediction is also = true; true negatives (TN) refer to the cases where the real phenomenon of the entry to be classified = false and the prediction is also = false; False positives (FP) refer to the cases where the real phenomenon of the entry to be classified = false and the prediction = true; false negatives (FN) refer to the cases where the real phenomenon of the entry to be classified = true and the prediction = false.

The second metric is Cohen's Kappa when we are confronted with a multi-label classification problem, sometimes the accuracy does not provide a complete picture of the model's performance, in this case we have to use this metric [9]. The ideal value for this metric must be very close to 1, a value equal or lower than 0 shows that the classifier is not very useful, it is calculated from (4) :

$$K = 1 - \frac{1-p_o}{1-p_e} \quad (4)$$

Such as : p_o is the observed value and p_e is the expected value.

Concerning the noise that can cause false alarms, we propose a double verification mechanism that is applied at the local level ; by the parent sentinel as well as the central level by the remote server. The latter, uses the data collected during its training as well as the data gathered from the vicinity of the sentinel signaling the alarm.

V. The Meteorological Phenomena Targeted By Our Sentinel

The specifications describing the operation of our electronic sentinel stipulate that its use can be oriented towards the detection and monitoring of several meteorological phenomena, depending on their characteristics and specifications. Nevertheless, in this paper and in order to fully understand the functioning of our sentinel, we focus on two almost opposite meteorological phenomena ; namely forest fires and floods. Thus, we will focus on the criteria for the detection of each phenomenon by our electronic sentinel.

A. Forest Fires

This phenomenon concerns fires that spread in forest areas as a result of high temperatures, causing water scarcity and evaporation in plants. These become a fuel for the flames, ignited by a simple spark [1]. The main causes of forest fires are global warming, lightning, lack of rain, etc. The detection of this phenomenon by the electronic sentinel is based on the following sensors [2] :

- DHT22 informs us of a sudden rise in temperature and a drop in humidity.
- BMP180 Barometer detects a rapid decrease in barometric pressure.
- MQ2 detects smoke.
- MQ9 detects CO.
- MQ135 detects CO_2.
- ARCELI 5 PCS detects very low soil moisture.

B. Floods

A flood is the submergence of an area by fresh or salt water, it can be slow or sudden. There are usually small or large floods caused by rivers or streams, and upwellings caused by intense rainfall [1]. The detection of this type of phenomenon by our electronic sentinel is based on the following sensors [2] :

- Raindrops : which informs us about the presence of precipitation.
- DHT22 informs us of an abrupt increase in humidity.
- ST045 which gives us the amount of water that fell.
- ARCELI 5 PCS detects humidity and the rise of the water level in the ground.

Since each electronic sentinel is equipped with a GPS beacon, the exact position of the phenomenon's trigger will be sent directly to the concerned services via the remote server. In the case of a forest fire, the civil protection services will be the ones concerned by this information. Whereas for a flood, the alarm will be intended for the technical services of the local authorities who will be responsible for setting up an evacuation plan.

VI. Simulation And Results

A. Simulation Parameters

Through this study, we recommend highlighting the contribution of our intelligent electronic sentinel in the early detection of meteorological phenomena, as well as the triggering of emergency situations and the appropriate behaviour for each one.

The artificial intelligence aspect must be put into practice for the automatic detection of phenomena, passing through two different phases : the first is the trainingphase, while the second is the test phase [3]. Therefore, it would be easier for our electronic sentinel to recognize more easily the triggering of a proven meteorological phenomenon of a false alarm, which leads us to simulate the two meteorological phenomena we have just mentioned, forest fires and floods in the direct environment of our sentinel.

For the first forest fire phenomenon, we simulate the setting of a fire next to the parent sentinel and the child sentinel. This implies that the DHT22 ambient temperature and humidity sensor will detect a significant increase in temperature and a decrease in humidity. Thus the BMP180 barometer detects a significant drop in barometric pressure and as our parent sentinel implements the naive Bayes algorithm then it automatically interrogates the MQ2, MQ9, MQ135 sensors to be informed of the presence of smoke and high CO_2 and CO concentrations in the air [10]. At this point, the parent sentinel triggers a local emergency situation and asks the daughter sentinel to send her the measurements collected by the ARCELI 5 PCS sensor to check the soil moisture, if it turns out to be very low then it triggers an emergency situation (forest fire) and sends an alarm containing its GPS position to the remote server.

In order to better monitor and pinpoint this fire, the electronic sentinel intensively collects all physical quantities every 10 seconds instead of every minute. In a normal situation, the electronic sentinel stores the measurements taken during 30 minutes in its hard disk and sends them in a single burst, but in an emergency situation it automatically sends all the measurements every 10 seconds to see the evolution of the situation in real time. We also implement false alarms (forest fire) such as a rapid increase in temperature, a sudden drop in barometric pressure, very low soil moisture but no smoke or CO and CO_2 emanation.

As for the floods, we simulate a heavy downpour next to the parent sentinel and child sentinel. This implies that the Raindrops sensor will detect rain falling and the DHT22 ambient temperature and humidity sensor detects a significant increase in humidity.

Since our parent sentinel implements the naive algorithm of Bayes then it automatically interrogates the ST045 and ARCELI 5 PCS sensors located in the child sentinel, to be informed of the amount of water falling and soil moisture [10]. If the values received by the child sentinel are very important, then the parent sentinel triggers an emergency situation (flooding) and sends an alarm containing its GPS position to the remote server. To monitor the evolution of this flood in real time, the parent sentinel performs intensive environmental measurements every 10 seconds and sends them automatically instead of 30 minutes (in one burst).

On the other hand, we set up false alarms (flooding) such as a rapid increase in soil moisture or air humidity but without any increase in water level by the ST045 sensor. To highlight the contribution of our electronic sentinel for the detection of meteorological phenomena based on the Bayes naive algorithm, we realize two variants of our simulation, each of them representing a different situation.

The first variant concerns emergency behaviour during a forest fire. We repeat the same situation every 20 minutes followed by an automatic reset of the sentinel after 10 minutes.

The second variant concerns emergency behaviour during a flood. We repeat the same situation every 20 minutes followed by an automatic reset of the sentinel after 10 minutes.

The third variant concerns the behaviour of our sentinel during a succession of false forest fire alarms, followed by flooding every 20 minutes. An automatic reset of the sentinel after 10 minutes is necessary.

Our simulation involves three scenarios :

In the first scenario the electronic sentinel encounters no emergency situation.

In the 2nd scenario the electronic sentinel encounters an emergency situation but before the training carried out by the naive classifier of Bayes.

In the 3rd scenario : the electronic sentinel encounters an emergency situation, but after the training carried out by the naive classifier of Bayes [7].

As a performance criterion we use the throughput received by the remote server. In our case the throughput represents the useful transmission rate (successfully received messages) sent by the electronic sentinel to the remote server [10]. The calibration values for the detection of the two weather phenomena by each sensor are shown in table II [8] :

TABLE II. THE CALIBRATION VALUES FOR THE DETECTION

Meteorological phenomena	Sensor	Calibration values
Forest fire	DHT22	Air temperature >=45
		Air moisture<=15%
	BMP180	Barometric pressure <500 hPa
	MQ2, MQ9 and MQ135	Amount of particles >= 800ppm
	ARCELI 5 PCS	Soil moisture <=10% water volume <= 0.621cm^3
Flood	Raindrops	Output D0 = 0 Or A0 = 0V
	DHT22	Air moisture >=60%
	ST045	Voltage >= 550 mV
	ARCELI 5 PCS	Soil moisture >= 48% or water volume >= 4.529cm^3

B. Results

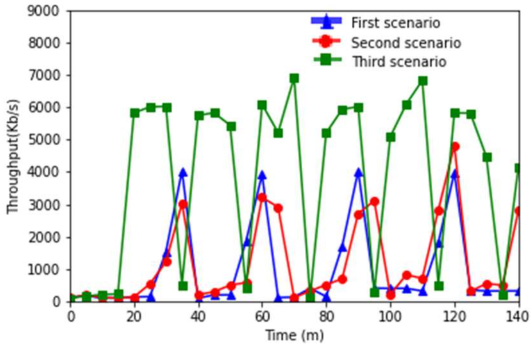

Fig. 7. The throughput(kb/s) received by the remote server first variant (forest fires)

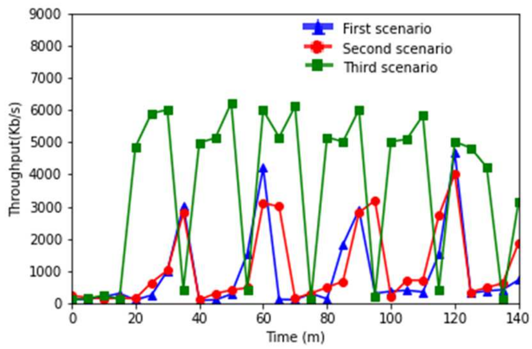

Fig. 8. The throughput(kb/s) received by the remote server second variant (flooding)

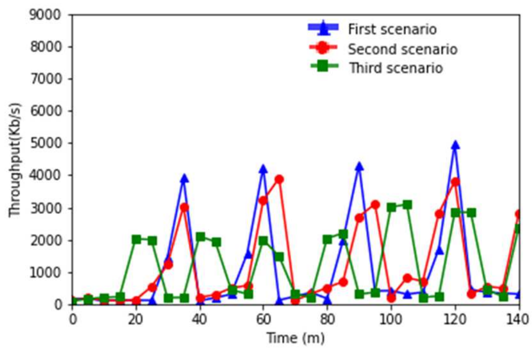

Fig. 9. The throughput(kb/s) received by the remote server third variant (succession of false alarms)

C. Results Discussion

In Fig. 7 related to the forest fire phenomenon, we observe that the throughput (kb/s) received by the remote server is higher (reaching 6000 kb/s and more) when it is the third scenario and this during the whole monitoring period of this phenomenon. Whereas for the second and first scenario, we notice peaks of relatively low throughput efficiency, centred only around the periods when the periodic reports are sent (every 30 minutes) ; the behaviour adopted by the sentinel during normal situations.

In Fig. 8 concerning the flood phenomenon, we notice almost identical evolutions to the previous figure with a slight decrease in throughput for the three scenarios.

In Fig. 9 relating to the succession of false alarms, we observe almost identical evolutions to the previous figures for the first and second scenario, while in the third scenario we notice a very low throughput which does not exceed 3000 kb/s and over short periods of time (when a false alarm is triggered).

According to the results we have obtained, we can clearly see the impact of our intelligent system based on the naïve Bayes classifier for the detection and monitoring of meteorological phenomena on the proper functioning of our electronic sentinel. This intelligent system is based on two different phases : training and test phase.

The first phase allows our electronic sentinel to memorize the characteristics of each meteorological phenomenon. While the second phase helps our sentinel to recognize the type of phenomenon and the appropriate behaviour to follow, based on the characteristics acquired in the training phase.

For electronic sentinels with a period of training beforehand in the two phenomena studied in this paper (forest fires and floods), it is noted that they quickly detect proven emergencies and false alarms. For emergency situations, the electronic sentinel triggers an exceptional and massive sending of data every 10 seconds to ensure real-time monitoring of the evolution of the phenomenon.

For false alarms, the electronic sentinel initiates a real-time monitoring via an exceptional data sending to the remote server, while ensuring the veracity of the situation if it is declared as a false alarm, then this exceptional sending is quickly abandoned.

On the other hand, electronic sentinels without this intelligent weather detection system based on the naïve Bayes classifier or a prior period of training, are unable to detect the type of phenomenon in question and its veracity. Even worse, they do not trigger any alarm and continue normal behaviour, depriving the remote server and its operators of real-time monitoring of the weather phenomenon. Concerning the evaluation of the algorithm's performance using the two metrics mentioned above, we obtained the following results during the test phase :

- Accuracy = 97.45% = 0.97.
- Kappa = 91.88 % = 0.91.

This shows that our algorithm performs well, despite the fact that there are still a number of false positives and negatives, but it can be considered quite reliable.

VII. Conclusion

Over the last decades, human activities have caused the release of large amounts of polluting substances of all kinds and greenhouse gases, leading to the global warming of our planet. The direct consequences of this global warming are the aggravation of meteorological phenomena such as floods, droughts and forest fires, which are constantly increasing and spreading, thus affecting entire populations.

Our goal in this paper is to develop the upcoming sensor networks that must be free from energy consumption limitations, thus ensuring a significant data processing capacity and increased security of communications in the context of a network. Which leads us to bring together all these aspects during the design and prototyping of our electronic sentinel. Made up of several modules including a multitude of sensors, our electronic sentry is able to automatically detect and monitor various meteorological phenomena in real time. However, the implementation of these tasks combined with the triggering of the appropriate behavior for each situation falls within the domain of artificial intelligence.

Indeed, based on the concepts of the Learning Machine, our electronic sentinel learns about each meteorological phenomenon and stores its characteristics in the knowledge base. These characteristics will later be used by our electronic sentinel as references during the test phase, to avoid triggering false alarms following the detection of false emergency situations.

Finally, through this study we propose as perspectives for future works, to adopt new methods of software engineering, for the development of smart applications such as smart environments, smart agriculture, or smart cities, etc. Obviously, the next step will be combining the research field of electronic sentinels with the Internet of Things, in order to develop new algorithms for optimal management of data flows. Finally, we suggest building a network of electronic sentinels to contribute to the sustainable development of large geographical areas: city, region, country, etc.

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