Urban Mobility in Smart Cities Using Low-Cost and Energy-Saving Wireless Sensor Networks

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***Abstract*—A wireless sensor network (WSN) is a specific technology that helps in creating smart cities. Their aim is consists in creating a network containing many nodes of intelligent sensors that can measure multiple parameters of interest for better city management, and a control of urban traffic (fluidity of traffic at an intersection). Each network node exhausts its energy because the battery capacity is limited.**

In this paper, we propose to study the problem of wireless sensor networks in smart cities, focusing on low-cost and energy saving. It is necessary to study architecture of a sensor node which is characterized by a limited energy capacity, making the optimization of the energy consumption in the network the major constraint to prolong the network lifetime. We will discuss the different factors involved in the consumption of energy and we will present some techniques to preserve it.

In this work, we will present an overview of our solution for energy conservation in the WSN. We will describe our solution which aims to avoid frequent transmission packets of data sent to the light controller. Then, we will detail the two simulators (GLD and SUMO) that we have used. Simulation results have shown that our solution enables minimization of number of packets sent, and therefore reduce the energy consumption, moreover, a lifetime of the network will be greater.

Keywords—WSNs, Smart cities, energy saving, urban traffic, energy consumption

I. Introduction

In this article, we are interested in the management of traffic lights in an urban road network [1], in order to reduce traffic jams and slowdowns. Traditionally, intersections traffic lights are run by controllers that define and implement a sequence predetermined (called light plan), alternating green and red lights without consideration changes in traffic.

In contrast to the traditional management of lights [2], sensor networks should ensure a more adequate quality service. This technique was developed by several researchers that have deployed sensors on each line of an intersection in order to better manage traffic. The sensor power capacity must be used efficiently [3], in order to maximize network lifetime [4,5,6]. Once a sensor node has exhausted its energy, it is considered failing. We describe the problem of energy consumption in sensor networks in the case of urban traffic (Intersection [2]). We will also present the main solutions proposed in the literature, then we will propose our solution for the management of energy consumption in based on the literature and simulations: Application of wireless sensor networks for intelligent transport systems in the case of an intersection. The objective is to minimize the sensor power consumption, has late prolong lifetime by optimizing the number of packets of data sent to the controller.

This paper breaks down as follows:
1) To start with we introduce some work in relation to our subject; we propose architecture for sensor network deployed at an intersection.
2) Then on the second step, we will present the two simulators GLD [7, 8, 9] and SUMO [10], in order to model and simulate road traffic. The results of the simulation are used in the proposed algorithm to treat the problem posed.

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3) And finally, a conclusion is given to present the results and summarize the main contributions of our work and research perspective.

II. OBJECTIVE AND PROBLEM

Tubaishat and al. [11] and Zhou and al. [12] used the wireless sensors networks to manage traffic lights. The infrastructure used is shown on Figure 1. by setting the hypothesis that each lane has two sensors, the first sensor C1 is placed before the traffic lights, and second C2 is placed after, (d) is the distance between the two sensors. Moreover, a controller is present on the side of the road to collect sensors data. This model allows us to properly measure the length of queues and the average waiting time at a junction.

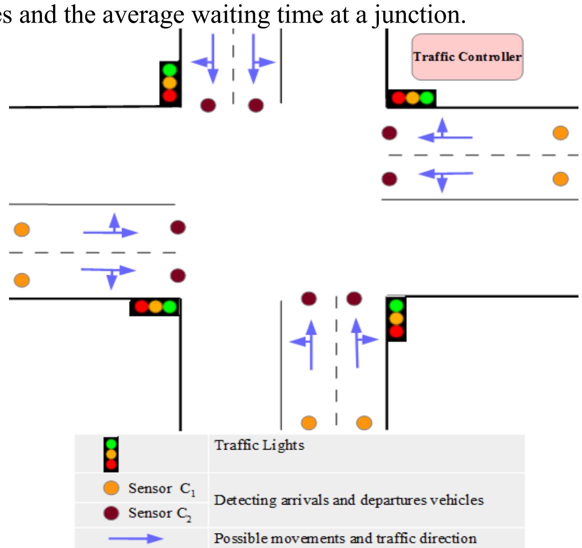


Figure 1. Simple intersection with two sensors per lane

We use in that case the electric-magnetic sensors [13]. They have the same behavior regardless of the junction: when a metal object passes over, this sensor detects variations in the terrestrial magnetic field. When a variation has occurred means that a vehicle is detected, in order to know its type (according to the intensity of the variations), to measure its speed or its length. Authors S. Faye and al. [14,15] made a comparison between models formerly presented.

TABLE I. THE LITERATURE MODELS

Authors	Number of sensor	Position	Management of energy sensor	Simulators
Tubaishat & al [11]	2/lane	At the light /Before the light	No detailed	GLD
Zhou & al [12]	2/lane	Ditto	No detailed	iSensNet

We provide a detailed aspect of the sensors energetic management that represents one of the major constraints (A sensor is limited by energy < 12 V). It is for this reason that current research focuses primarily on ways to reduce this consumption [16, 17].

A. *Architecture of a sensor node*

A sensor node is composed of four main units [18, 19, 20] (Sensing unit, Processing unit, Transceiver unit and Power unit), which are presented in Figure 2.

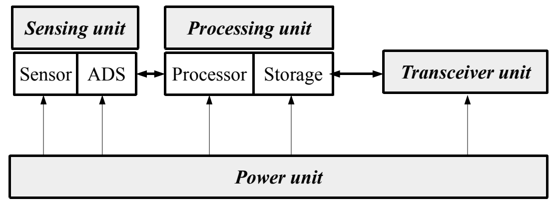


Figure 2. The components of a sensor node

Concerning the power unit, it's the battery which is an important component of a sensor. In general, its neither replaceable nor rechargeable. The limited energy capacity at the sensors is the main constraint for sensor.

B. *Energy consumption in WSN*

The energy consumed by a sensor node is mainly due to the following: Sensing, processing and communication of data [21]. We can classify them according to their energy consumption:

- In general, the capture energy represents a small percentage of the total energy consumed by a node. The treatment energy is low relatively to that required for communication [22,23].
- The communication power is divided into two parts: the reception energy and transmission energy. This energy is determined by the amount of data (number of packets) sent to the traffic controller, and the transmission distance, as well as by the physical properties of the radio module [24]. Let us note that the energy of communication represents the largest portion of the energy consumed by a sensor node. In our study, we interested in our study the number of data packets sent.

III. TOOLS SIMULATOR

Use In this part, we chose both GLD and SUMO simulators:

A. *Green Light District Simulator (GLD)*

GLD [7, 8, 9] is a program that performs discrete simulations of road networks. The full application consists of two part: an Editor and Simulator. The Editor enables the user to create an infrastructure (a road map) and save it to disk. The simulator can then load the map and run a simulation based on that map. Before starting a simulation, the user can choose which traffic light controller and which driving policy will be used during the simulation (i.e., it specifies traffic-lights green-red policy). A traffic light controller is an algorithm that specifies the way traffic lights are set during the simulation. Figure below shows the software interface [9]:

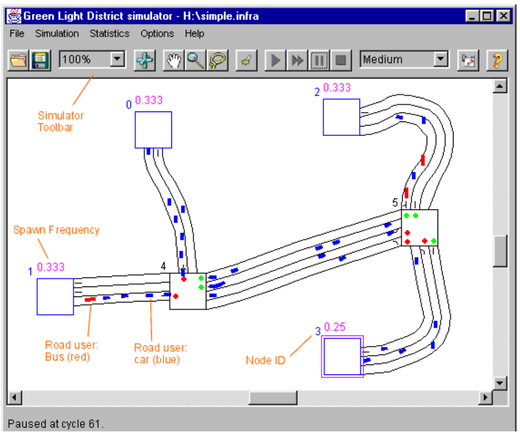


Figure 3. Green Light District Simulator

B. *Simulator of Urban Mobility (SUMO)*

SUMO is a simulator open source at a discreet time, continuous space and microscopic fully realized in C ++ to modelize road traffic flow [10]. Figure 4. shows the interface of the SUMO software before (left) and after (right) running simulation.

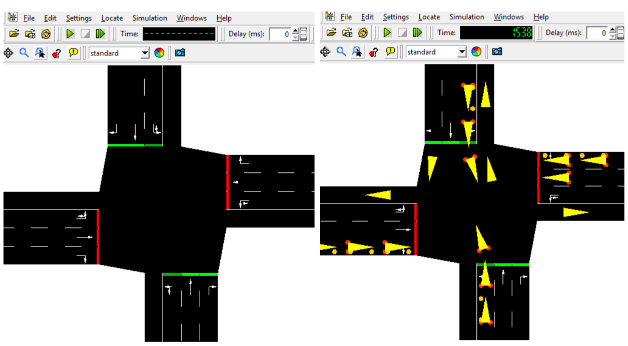


Figure 4. Simulator of Urban Mobility

Building a network (map) in contrast to GLD, is not necessarily automated by an interface, but based on the construction of an XML file, which can be obtained in many ways. The advantage of SUMO may implement more complex structures. Studies are outstanding. We will present them in future work. Order, to compare them with the results of GLD simulator.

IV. RELATED WORK

A. *Global overview of our solution*

After the description of the main causes of energy consumption in WSNs used in traffic management, in this step we are going to present our solution to minimize this consumption. The following diagram (Figure 5.) provides an overview of our method, and outstanding research related with our subject.

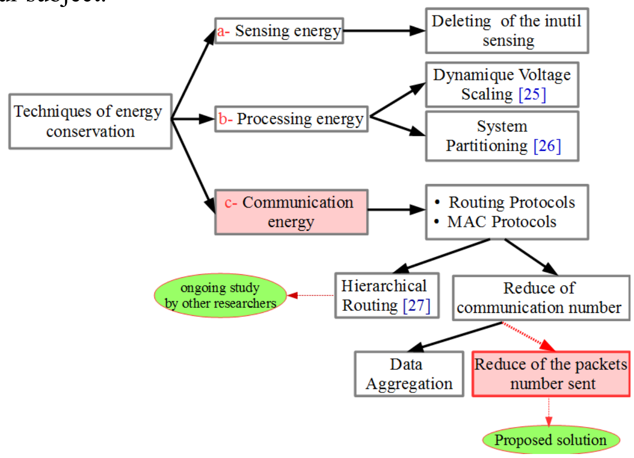


Figure 5. Global overview of our solution

The sensor of energy can be saved either to (a) Sensing level, (b) Processing level or (c) Communication level. We interested in level (c).

B. *Method and proposed solution*

This part we suggest a method based on the number of messages sent by the sensor C1 let's describe the method in details.

When a crossing of vehicle is detected by a sensor, it produces a detection message and sends it to the controller in order to real time traffic management. However the repeated forwarding of the messages generates an important consumption of energy. To reduce energy consumption, we suggest reducing number of sent packets. We define the presence of a vehicle as the fact of being located in the detection zone of the sensor. Besides, each detection or vehicle passage is referenced by the time (T). Figure 6. illustrates the vehicles detection through a fixed sensor [28].

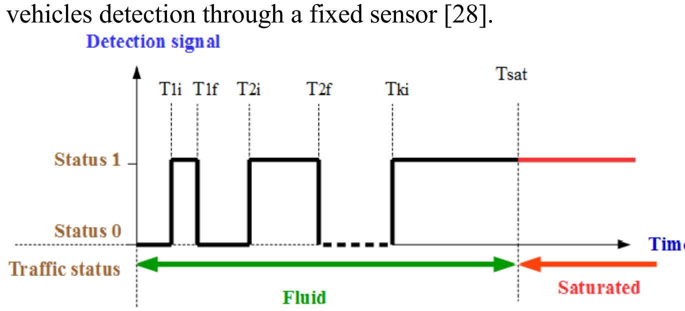


Figure 6. Detection signal of the vehicles by sensor C1

T_0 : Date and time of the performance

k : Number of vehicles (between the 2 sensors) with $k = \{1; 2; 3; \ldots\}$

T_{1f} : End of the first vehicle detection

$T_d = T_{ki} - T_{kf}$: Time of the vehicle detection

T_{sat} : Starting time from which the queue is saturated.

The sensor involves two status:

- Status 0: No vehicle detected
- Status 1: Vehicle detected. Were interested in status 1.

When a vehicle has just been detected by the sensor, the latter stands (status 0), we there for say that it is the beginning of the detection. When the detected vehicle goes by the sensor changes its status (status 0) that's the end of the detection. The time elapsed between the change of the sensor from $0 \to 1 \to 0$ is called the detection duration (Figure 6). We also define T_{sat} the time when the queue is saturated. When $T_d \geq T_{sat}$ that mean queue is saturated.

- *Algorithms of Packets Transfer:*

In this sub-section, we will present the average number of the sent packages during the algorithm execution. It's based on the simulations which were performed on a intersection with probabilities entry the nodes (es auch genannt wird spawn frequency) 0.3; 0.6 and 0.9. We will present the graphs according to the two following algorithms:

a) Classic Algorithm:

if $T_d > T_{sat}$
then Transfer of packets
else Normal functioning

In the previous cases (GLD) each simulation is launched during the 1000 cycles and estimate the average waiting time of vehicle. The latter is compared to the saturation time of the waiting line T_{sat}. We define T_{sat} is the average value of the AJWT (Results of the GLD - Section V).

The sensor (C1) measure the permanent arrivals (by verifying the classic algorithm), whereas the sensor C2 operate at a green light, which will to send a package to the C1 sensor (The line is freed).

TABLE II. TOTAL NUMBER OF SENT PACKETS DURING 1000 CYCLES CLASSIC ALGORITHM

Spawn Frequency	0.3	0.6	0.9
T_{sat} **(Average of AJWT)**	11.49	27.89	30.31
Total Number of sent packets	382	638	709

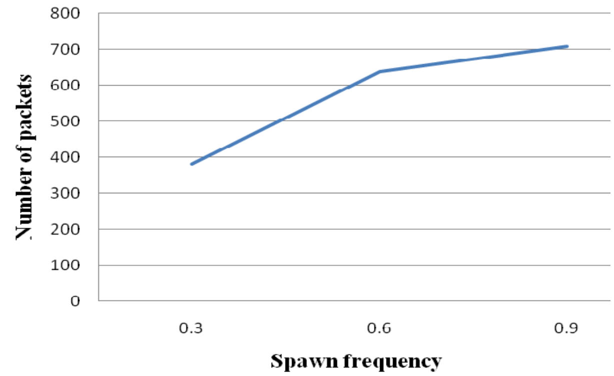
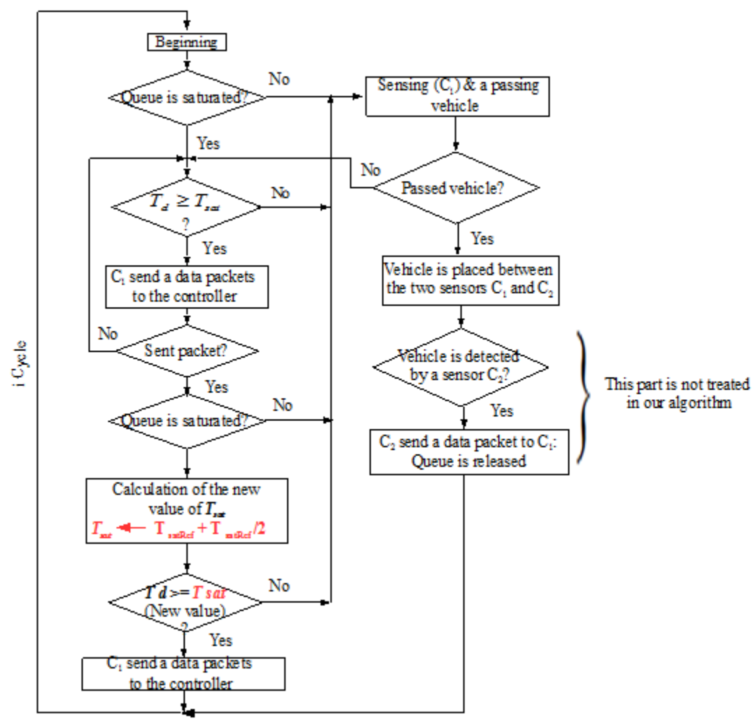


Figure 7. Total number of sent packets during 1000 cycles-Classic Algorithm

b) Organizational Chart :

The flowchart in the figure below shows the general operation of our proposed algorithm. It shows the time or a node can transmit a data packet to the traffic controller. The main objective of our work is to conceive an algorithm (using simulation data) which minimizes the number of packet sent in order to save energy and increase the lifetime of the network.



c) Proposed Algorithm:

In order to simplify and make our algorithm efficient, we focused on the objectives indentified previously. The updated algorithm (Proposed) T_{sat} (Average of AJWT, we note $T_{sat} = T_{sat\,Ref}$. The value of AJWT is compared to the new value of T_{sat} (semi-dynamic). We define T_{sat} as following:

$$T_{sat} = T_{sat\,Ref} + \frac{T_{sat\,Ref}}{2}$$

A part of the algorithm is described below: (Developed by programming language C Sharp)

```
                //Calcul Tsat
                tSatRef = rowsValues.Average();
                double tSat = tSatRef;
                bool paquetEnvoye = false;
                //Algorithm
                foreach (double ajwtMoy in rowsValues)
                {
                    if(ajwtMoy >= tSatRef)
                    {
                        nbBrute++;
                    }
                    if (ajwtMoy >= tSat)
                    {
                        ++nbrPaquetsEnv;
                        paquetEnvoye = true;
                    }
                    else
                    {
                        paquetEnvoye = false;
                    }
                    if (paquetEnvoye)
                    {
                         tSat = tSatRef + tSatRef / 2.0;
```

TABLE III. TOTAL NUMBER OF SENT PACKETS DURING 1000 CYCLES PROPOSED ALGORITHM

Spawn Frequency	0.3	0.6	0.9
T_{sat} (Average of AJWT)	Semi-dynamic		
Total Number of sent packets	196	329	362

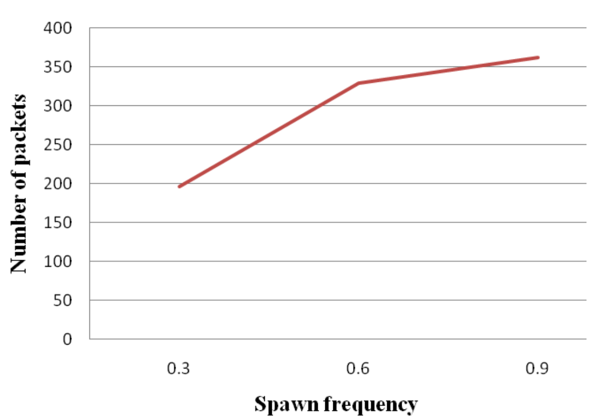


Figure 8. Total number of sent packets during 1000 cycles Proposed Algorithm

Figures 7. and 8. show the number of packets sent by the network C1 sensor during 1000 cycles according to Spawn frequency. Figure 7. shows that the number of packets sent is high (709 packets/C1 for the entry probability of hedge knots 0.9). We also notice that this number increases with the entry probability of the knots, this is justified by the fact the total of the waiting time increases as well as length of the waiting. However, if we compare the graphs of sent packets Figure 9. according to classic algorithm (normal) and proposed algorithm (Optimized) for the same spawn frequency, we remark that the number of sent packets by C1 sensor has decreased twice less.

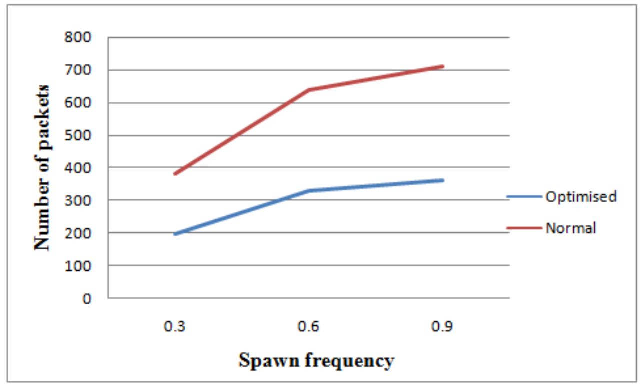


Figure 9. Comparison between the two algorithms

In our case, we chose a simple infrastructure (an intersection). A screen shot of the software is available in Figure 10.

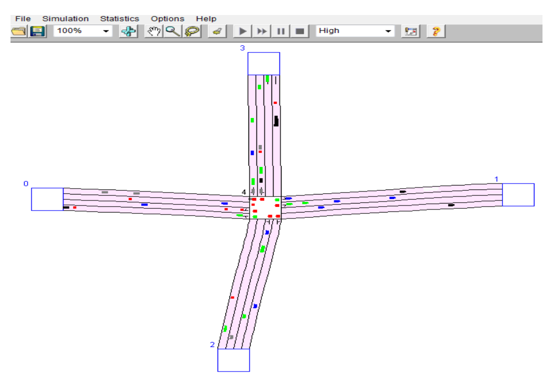


Figure 10. Green Light District Simulator

Road users are allowed to: Turn left, Go straight ahead, or Turn right, as shown in Figure 11.

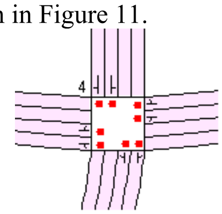


Figure 11. Direction of movement on each line

While running a simulation, GLD can track different types of statistics such as the number of road users that reached their destination, the average junction waiting time (AJWT) or the average trip time shows in Figure. 12.

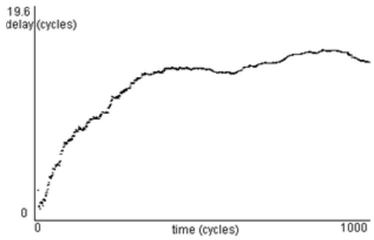


Figure 12 a) Spawn frequency 0.3

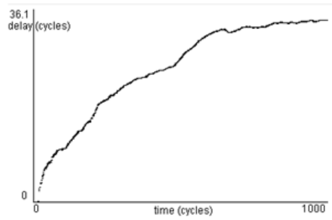


Figure 12 b) Spawn frequency 0.6

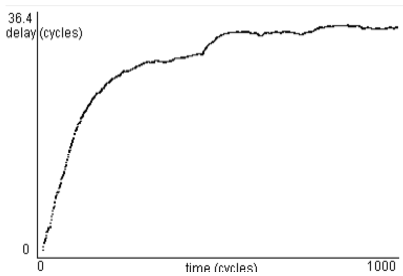


Figure 12 c) Spawn frequency 0.9

Figure 12. displays the average junction waiting time (AJWT) illustrated through the simulation of 1000 cycles. The cycle being a time unit of GLD, and it corresponds to a software movement, the simulations were performed on an intersection with entry probability of edge node 0.3, 0.6 and 0.9 (for each cycle, for each edge node).
The enclosed table sums up the values achieved:

TABLE IV. RESULTS OF SIMULATION: AVERAGE AJWT DURING THE LAST 1000 CYCLES

Spawn Frequency	0.3	0.6	0.9
T_{sat} **(Average of AJWT)**	11.49	27.89	30.31

Simulation results are used in the algorithms mentioned previously [Section IV. B 1) and IV. B 1) 2)]

V. CONCLUSION AND PERSPECTIVES

In this paper, we presented a new method so as to decrease the energy consumption of a sensor network achieved in the urban traffic management.
Through simulation results, We demonstrated, that our present solution will achieve better performances as for as low-cost and energy-saving are concerned in communication data in the case of a simple intersection.
Concerning our future work, we are planning to set a new approach with the same method but using a more complex infrastructure: Several intersections, sensor C2 and the algorithms that manage the traffic lights involving the SUMO simulator and then compare results with those obtained previously.

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