A Self-Powered Bluetooth Network for Intelligent Traffic Light Junction Management

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Abstract: Wireless Sensor Networks (WSNs) are increasingly used in Intelligent Transportation System (ITS) applications, especially in dynamic management of signalized intersections. This paper proposes a Bluetooth network architecture in order to monitor vehicular traffic flows near to a traffic light. The proposed architecture is characterized by a novel algorithm in order to determine green times and phase sequences of traffic lights, based on measured values of traffic flows. It is known that the wireless sensor networks are characterized by very low power devices, so the continuous information transmission reduces the life cycle of the whole network. To this end, the proposed architecture, provides a technique to power the sensor nodes based on piezoelectric materials which allow to produce potential energy taking advantage of the vibration produced by the passage of vehicles on the road.

Key–Words: Wireless Sensor Networks, Intelligent Transportation System, Traffic Lights, Queues Management, Piezoelectric materials

1 Introduction

1.1 WSNs for Road Monitoring Applications

One of the main targets of Intelligent Transportation Systems is to ensure road safety because the number of vehicles constantly grows up in cities. Road safety must be improved in traffic lights intersections where many road accidents occur for various reasons, including a wrong traffic lights management. Currently the most of traffic lights are implemented with fixed cycles or they are manually controlled introducing also human evaluation errors. Whereby several works focused on innovative traffic lights management techniques. Unfortunately, most of proposed solutions produce several problems, like wrong green-time balancing or excessive fuel consumption. These issues can be overcome thanks to modern technology and novel methodologies. In recent years, several studies have focused on the use of WSNs [1], many of which refer to road monitoring [2] because they are capable to make different measures on the monitored traffic area. In fact, the sensor nodes of the network can be placed anywhere and they are easy to manage. Through a distributed and clustered network infrastructure, capable to evaluate real time traffic flows, WSNs are particularly useful to monitor highly crowded roads and then they represents a concrete solution to road congestion problem.

1.2 Energy harvesting

In recent years, several energy harvesting applications have been developed in order to produce electric energy from vehicular, train or pedestrian traffic or from environmental vibration in general. Anyhow, there are not applications in ITS systems which can develop energy from used roads. For this reason, several kinds of energy sources have been investigated by researchers. A source of energy can be represented by vibrations because they are the most ubiquitous and can be found everywhere [3] [4]. In addition, another source is represented by the mechanical energy that can substitute solar energy and in several applications obtains more potentiality. In both cases, the objective regards a greater amount of energy generated as efficiently and economically as possible. The use of smart materials such as piezoelectric has been studied and developed in different scenarios [5] in order to harvest energy. In fact, an effective way for the electricity production is represented by the recovery of mechanical energy produced by vibrations. This can be obtained through the use of piezoelectric materials because their effect consists of the generation of an electric field produced by a mechanical deformation of the same piezoelectric material. In recent works, this technology has been applied in several application fields, like self-powered wireless sensor networks for data acquisition and processing [6].

1.3 Main Aim

This paper presents a novel methodology for intelligent traffic light junction management based on real-time information detected by self-powered Bluetooth [7] sensor nodes placed along road sections. The main aim of the proposed approach is to reduce the waiting time in traffic light queues. The paper is organized as follow: section 2 proposes main literature related works while section 3 describes the proposed network architecture. Section 4 proposes the experimental test- bed showing obtained simulations results. Finally, section 5 reports conclusion and possible future works.

2 Related works

2.1 Wireless Sensor Networks for Traffic Light Junction Management

The knowledge of traffic information represents a key aspect of intelligent transport systems (ITS). Currently, most of used monitoring systems are based on a wired communication infrastructure that increases maintenance costs and reduces architecture scalability. In order to solve these problems, WSNs can be used because they introduce a higher information quality due to a denser sensors placement in the monitored area. WSNs have been exhaustively studied and used in several fields, like agriculture [8], home automation [9], health [10] and industrial [11] [12] to mention some. Doubtless, one of the main application fields of this technology is signalized intersections management focused on waiting times and queue lengths reduction. In fact, real-time traffic detection, through a WSN, helps drivers to make decisions in order to optimize arrival time and to avoid queues. For these reasons several works in literature deal with WSNs used for road traffic monitoring and management. In [13] a solution based on a new network topology applied to sensor networks for road monitoring, in order to improve performance in terms of throughput and energy savings, is proposed. In [14] authors propose an algorithm that considers several values about traffic flow for green times calculation and phase sequences determination for each traffic light cycle. The proposed approach is an alternative to the traditional road intersections management system but its real implementation needs long periods for testing to evaluate its effective functioning. The approach proposed in [15] shows a technique for vehicles detection using magneto-resistive sensors. The authors show an algorithm that identifies vehicles through the analysis of signals received from sensors deployed along road. Simulations are performed on a simple phasing plan while it is not analyzed the possibility of phase changes depending on run-time traffic detected. A novel architecture in which sensor nodes detect road information in order to determines the flow model of the intersection is proposed in [16]. The same authors propose in [17] results obtained using one sensor and two sensors. Results show that the deployment of sensors close to each other produces the best performance in terms of data quality and, also, it reduces energy consumption of WSN nodes. A fuzzy logic algorithm used to determine green time duration at traffic lights is showed in [18] while authors of [19] propose a fuzzy logic controller and an innovative WSN architecture in order to dynamically enable or disable cameras, according to the real need, in a monitored signalized intersection. The approach proposed in [20] involves the use of a local fuzzy logic controller installed at each junction that derive the green time for each phase in a traffic-light cycle through a dynamic-programming technique. Moreover, the authors of [21] propose a fuzzy logic controller in order to dynamically adjust green time of traffic lights. According to the proposed approach, traffic flow can be detected by the single-axis magnetic sensors and transmitted through wireless sensor network. The time for vehicles passing during the green lights is dynamically adjusted through the fuzzy algorithm according to the current volume of vehicles. In [22] and [23] the authors propose an adaptive traffic light control algorithm. In order to determine the optimal green light duration, the proposed approach adjusts both the sequence and length of traffic lights in accordance with the real time traffic detected by WSN. An intelligent traffic signals control system based on a WSN is shown in [24]. Authors propose an approach that uses the vehicle queue length during red cycle in order to perform better control in the next green cycle.

2.2 Techniques for energy harvesting

In the last decade, the increasing cost of energy and related environmental problems have led researchers to investigate new energy sources [25]. The authors propose innovative mechanisms in order to reduce greenhouse gas emissions by increasing energy efficiency of existing systems. Moreover, other works introduce

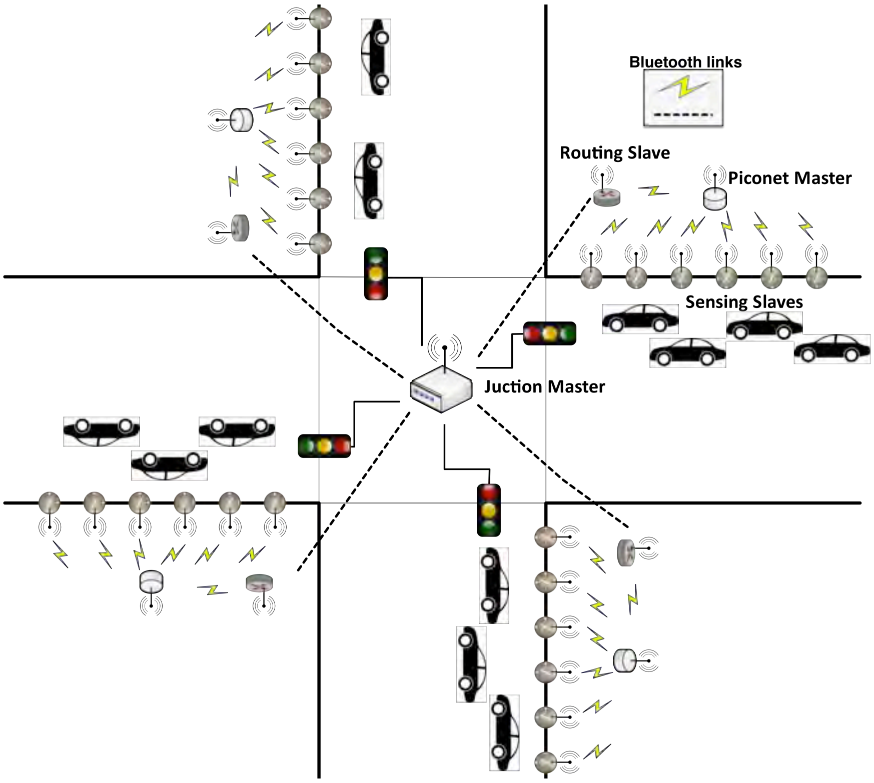

Figure 1: System Architecture

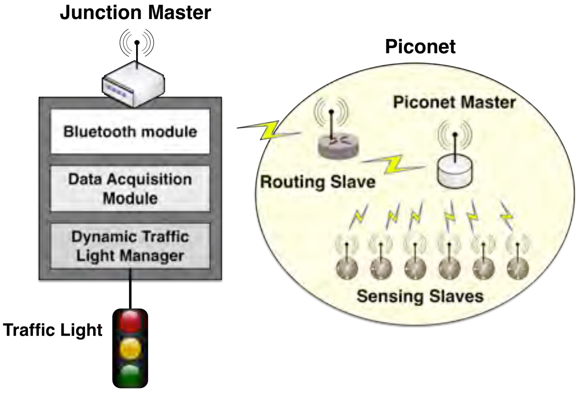

Figure 2: Main System Elements

novel solutions for energy saving and energy recovery both in civil and in industrial environments [26] [27] [28]. Instead, other authors focus on the energy harvesting using piezoelectric materials as very interesting research issues concern the energy recovery techniques using environmental mechanical vibrations. Recently, in the station of Shibuya (Tokyo), an energy collection system that uses a piezoelectric transducer [29] has been installed, under a proposal of the East Japan Railway Company. Moreover, in recent years, the Innowatech society has proposed several applications based on piezoelectric stack transducer for the energy production through vehicular traffic. After considering all these research and real-world applications aspects, some researchers [30] have recently shown a mechanical device for energy harvesting using piezoelectric bimorph bender transducer, which can recover energy from road, pedestrian and rail traffic. The use of piezoelectric bender devices and an innovative configuration that allow to transfer mechanical vibrations of the main box to the piezoelectric transducer represent the innovation of this technique.

3 System Architecture

3.1 WSN requirements

For a better interpretation of traffic flows, in a road-monitoring context, a fundamental condition is represented by the knowledge of the real-time situation of road sections. In order to ensure the timely processing of information coming from the road, it is necessary to realize an appropriate monitoring environment, based on appropriate technologies. This monitoring environment must guarantee several requirements including:

- real-time communication among network nodes;
- real-time scheduling of system tasks [31];

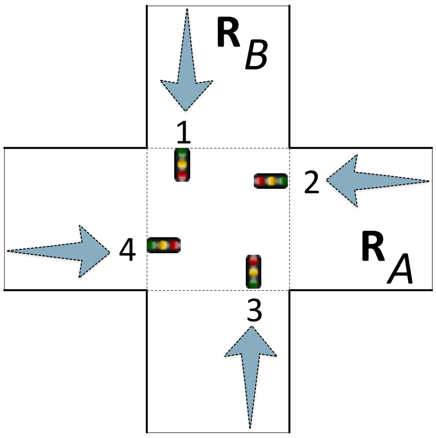

Figure 3: Road intersection

- performance predictability;
- transmission reliability [32];
- prevention and reaction to critical situations.

The proposed system, based on a Bluetooth [7] network, is characterized by architecture shown in Figure 1. It is important to underline that Bluetooth does not natively support real-time communications. As demonstrated by [33] [34], a deadline-aware scheduling should be introduced in order to ensure the satisfaction of real-time constraints. Anyhow, the architecture proposed in this paper is based on the standard Bluetooth protocol [7], without hardware or software changes. According to Bluetooth standard, a piconet is formed by a master node and a maximum of 7 slaves. If the network requires more than 7 slaves then it is possible to implement a scatternet, a type of adhoc computer network consisting of two or more piconets. Scatternets can be formed when a member of one piconet participates as a slave in another piconet. This slave transmits data among members of both networks. In our approach, the traffic light junctions are monitored using appropriate nodes, Sensing Slaves (SS), provided with magnetic sensors in order to detect the presence of ferrous objects (vehicles). The data gathered by the SS nodes is then forwarded to their Piconet Master (PM) which collect information of the piconet and forward them to the Routing Slave (RS) which takes care of data exchanging between piconets. The information gathered is forwarded among piconets to the Junction Master (JM), which has processing functions. All modules that characterize the JM are shown in detail in Figure 2:

- Bluetooth communication module;
- Dynamic traffic light manager module;
- Data acquisition module.

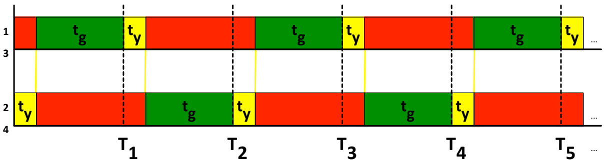

Figure 4: Periodic traffic lights task scheduling

3.2 Dynamic traffic light manager module

The considered traffic light junction is shown in Figure 3. The traffic lights 1 and 3 have to be considered as one traffic light because they have the same green and red times. The same goes for traffic lights 2 and 4. For this reason, we indicate with R_A the road containing traffic lights 1 and 3 and R_B the road containing traffic lights 2 and 4. The functioning of each traffic light can be approximated to a periodic task with period T_i and duration t coincident with the time of the traffic-light cycle. As shown in Figure 4, in a standard management in which priorities are not considered, every traffic light after a period of time T_i has a fixed green time (t_g) and a fixed yellow time (t_y), while the following period is red. In this case, the traffic light does not take into account the dynamic queue behavior. In fact green and red times will be always fixed although a road has a long queue of vehicles. Due to this issue, it is necessary to realize a dynamic scheduling algorithm that takes into account the real number of vehicles waiting near traffic lights. Figure 5 shows a road section of length L subdivided into smaller sub-sections, each one of length l_i. Each subsection l_i is identified by a Sensing Slave which main task is to detect vehicles presence. A special housing placed on the sidewalk contains the SS equipped with a magnetic sensor. It measures the earth's magnetic field distortion caused by the presence of metal components of a vehicle near the sensor. Through the Bluetooth protocol, the information gathered by the SS is forwarded to the PM that forwards them to the RS. The parameters that must be chosen at system design time are the following:

- the length (L) of the entire monitored section;
- the length (l_i) of every single sub-section;
- the approximate speed (v) with which sections are crossed.

Generally, cars represent most of waiting vehicles at traffic lights. Considering that the average length of a car is between 3.5 and 5 meters, the length of each subsection (l_i) can assume values between 4 and 8 meters. Each sub-section length must be adapted, according to the communication protocol. According to the specifications of Class 1 Bluetooth devices, for

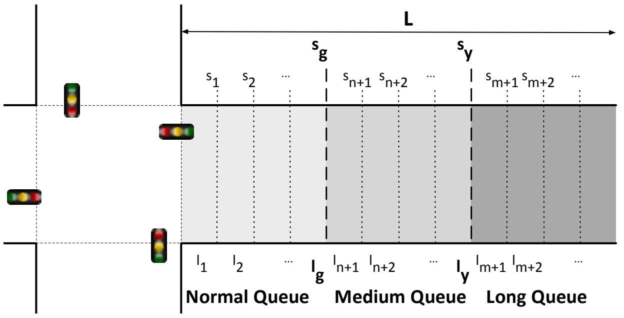

Figure 5: Monitored road section

example, the SS/RS nodes can be placed every 10 meters while the PM nodes every 25 meters, while the JM can be placed at the end of the road near the traffic lights. We approximate the average speed (v) of a generic vehicle crossing a traffic light intersection at the value of 15Km/h. The l_g value indicates the maximum value by which the queue at the traffic light is considered normal, while l_y indicates the maximum value by which the queue at the traffic lights is considered medium; over this value the queue is considered long. The number of sub-sections is calculated through the ratio L/l_i while the l_g value can be determined by the following equation (1):

$$l_g = \frac{\left(\frac{L}{l_i}\right)}{3} + 1 \tag{1}$$

The total number of sub-sections is divided by three but another has been added to increase the length of the area where the queue, at the traffic lights, is considered normal. The l_y value, therefore, is calculated according to the equation (2):

$$l_y = \frac{L}{l_i} - l_g \tag{2}$$

As shown in Figure 6, in case of vehicles detection in a section $l_i < l_g$ the traffic light works under standard conditions, with period T_i, green time t_g and yellow time t_y. On the contrary, there is medium queue in case of vehicles detection in a section $l_g < l_i < l_y$. In this case it is necessary to calculate the new green time t_{grt} based on sub-section in which vehicles have been detected; instead for $l_i > l_y$ there is a long queue condition. The crossing time of a single subsection can be easily estimated through the equation (3):

$$t_i = \frac{l_i}{v} \tag{3}$$

where l_i and v are known parameters, as they represent respectively the length of the i-th section and the approximate crossing speed of each single route.

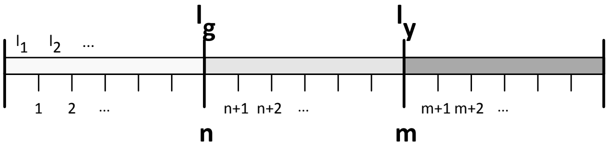

Figure 6: Sections subdivision

According to the estimated queue length, the green time must be recalculated in case of medium or long queue. The standard green time t_g and the real-time green time t_{grt} can be calculated through the following relations:

$$\begin{cases} t_g, & \text{if } l_i \leq l_g \\ t_{grt} = t_g + \frac{l_j + l}{v}, & \text{if } l_g < l_j \leq l_y \\ t_{grt} = t_g + \frac{l_k + l}{v}, & \text{if } l_k > l_y \end{cases} \tag{4}$$

with $j = n+1, n+2, \ldots, m$ and $k = m+1, m+2, \ldots$. The terms $(l_k + l)/v$ and $(l_j + l)/v$ represent a space and speed ratio, and then a time that must be added to the green time of traffic lights in order to slightly increase the total green time and to allow a better queue draining. This time value takes in account the i-th sub-section in which the sensor detects a vehicle. The road that has the longest green time has higher priority. Each traffic light independently calculates, during each period, its green time in order to determine its priority level according to the equation (5):

$$\begin{cases} p_i = t_g, & \text{if } l_i < l_g \text{ with } i = 1,2,3,4 \\ pi = t_{grt}, & \text{if } l_i > l_g \text{ with } i = 1,2,3,4 \end{cases} \tag{5}$$

where p_i is the priority of the i-th traffic light. As previously said, traffic lights 1 and 3 must be considered as unique, since they have the same green and red time. The same is true for traffic lights 2 and 4. So the priority must be entirely referred to road R_A, containing traffic lights 1 and 3, and the road R_B, containing traffic lights 2 and 4. The algorithm determines the road with highest priority at the end of the period T_i, determining which traffic lights needs more green time. During each period, the priority p_i of each traffic light is calculated or one or more times in order to determine the priority of the road. At the end of the period T_i the algorithm evaluates the road with highest priority determining which traffic lights needs more green time. The priority of each road is given by the sum of the priorities of the traffic lights which is divided by two in such a way that the actual time is not given by the sum of the times of each traffic light, because otherwise the time would be too long, but by an average value. The priority of each road is calculated through equation (6) and (7):

$$P_{R_A} = \frac{(p_1 + p_3)}{2} + \frac{\Delta_A}{2} \quad (6)$$

$$P_{R_B} = \frac{(p_2 + p_4)}{2} + \frac{\Delta_B}{2} \quad (7)$$

The Δ value (positive or negative) is calculated considering both the road with highest priority and the traffic light color at the end of the period. Moreover, Δ is divided by 2 in order to avoid that it may assume a very great value (green time too long).

3.3 Self-power technology

In order to supply power to Bluetooth sensor nodes, the system configuration is based on a bimorph piezoelectric transducer rectangular clamped to an extreme [35]. Two piezoelectric outside (active layers) and a thin metal plate in the middle section (passive layer) form the converter. This converter is made of lead zirconate titanium (PZT-5A), a material with a high efficiency and flexibility in the charge production. The passive layer performs both the connection between the two active layers, and the distancing of the same from the neutral axis, resulting in increased deformations and electric potential [35]. To exploit the potential of this technology, parallel and serial configurations have been analyzed. The parallel configuration involves the construction of three electrical connections for the extraction of the converted charge, while in the serial configuration it is necessary to adopt two electrical connections. The Figure 7 shows the constructive characteristics of the two configurations adopted, with the electric connections and the polarization directions [36]. In order to gather the external vibrations, caused by the passage of vehicles, and to transform them in energy [37], the Energy Harvesting Device (EHD) will be installed within a road cavity. The energy harvesting system consists of a piezoelectric transducer bonded on the surface of the steel beam subjected to external impulse [38]. The beam, shown in Figure 8, undergoes a tensile stress and a compression producing, as a consequence, an electrical potential. Through an electrical circuit, this potential difference, generated at the extreme poles, is converted into electrical energy.

3.4 Electrical circuit model and battery charging system

It is necessary to highlight that the energy obtained from the piezoelectric transducers is not directly usable by electronic devices due to random variations of power and voltage over the time. For this reason, a suitable circuit for the management of gathered power is required. In fact, the effort made to obtain efficient transducers may be lost without the use of proper adapters able to convert signals of a few millivolts, or even less, without substantial losses. Moreover, these circuits consume energy and so they must be able to shut down when the source of energy is not enough to power the device in order to avoid unnecessary energy consumption. Anyhow, the power management circuit must be able to automatically switch-on (self-starting) when the energy increases. The general structure of the power manager circuit can be divided in three interfaces (Figure 9 a). Generally, the output voltage of a piezoelectric generator is characterized by a pseudo-periodic behavior and assumes positive and negative values alternately. For this reason, a rectifier circuit [40] is always necessary. The circuit uses a small piezoelectric transducer in order to convert the mechanical vibration into an AC voltage source that is powered inside the bridge rectifier internal of the LTC3588 (piezoelectric energy harvesting power supply). It can recover small vibrations and generate system power instead of using traditional batteries. The LTC3588-1 is a very low quiescent current power supply, specially designed for energy recovery applications or step-down at low current. It can directly interface with a piezoelectric transducer or another AC power source, rectifying the voltage wave-

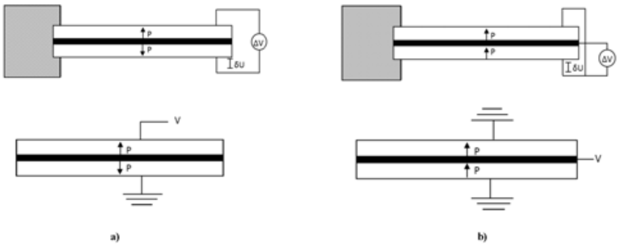

Figure 7: Bimorph piezoelectric. a) Parallel configuration (left); b) Serial configuration (right)

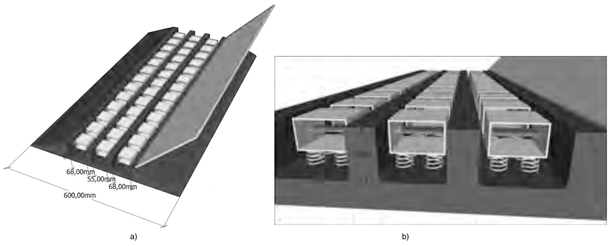

Figure 8: a) Road cavity; b) Detail of the EHD installed inside the speed bump with cavity

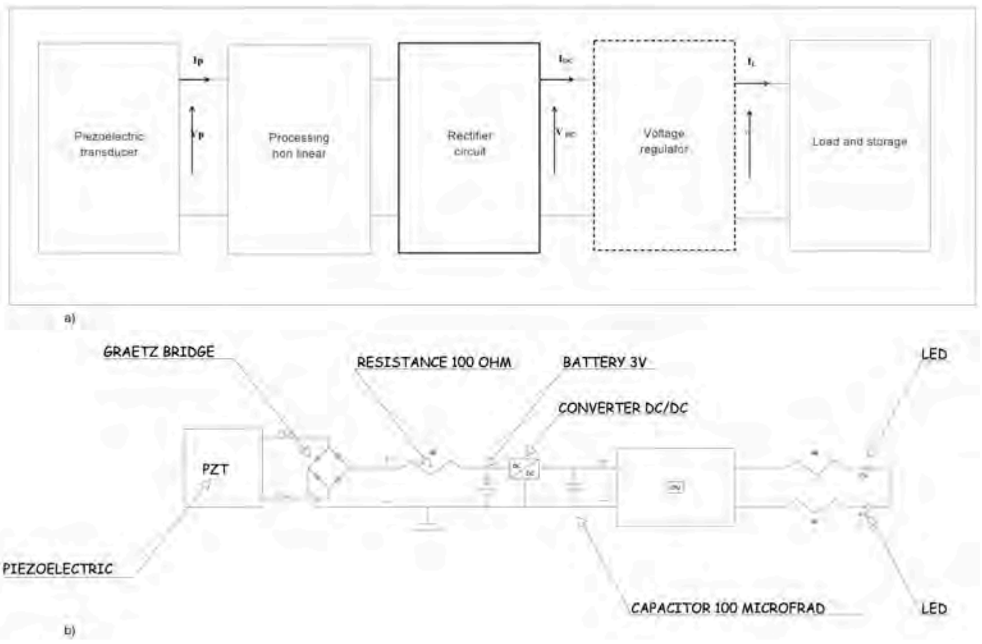

Figure 9: a) General structure of a power manager circuit [39]; b) Energy harvester simulation model including mechanical part and bridge diode rectifier power conditioning

form and storing the energy recovered in an external storage capacitor. At the same time it dissipates the energy in excess through an internal derivation regulator, maintaining an output voltage regulated through a buck regulator with high efficiency. Two differential inputs, PZ1 and PZ2, which rectify the AC inputs, can access the full-wave bridge rectifier inside the LTC3588-1. The rectified output is stored in a capacitor to the VIN pin and can be used as an energy reserve for the buck converter. The low loss bridge rectifier has a total voltage drop of about 400 mV with typical piezoelectric currents which are normally equal to about 10 mA. Moreover, this bridge is able to conduct currents up to 50 mA. On the contrary, the buck regulator is enabled as soon as an enough voltage is available on VIN in order to produce a regulated output. In order to control the output through the internal feedback of the detection pin VOUT, the buck regulator uses an algorithm for hysteretic voltage. Furthermore, the buck converter loads an output converter through an inductor to a value slightly higher than the regulation point. At this point, the current inductor is increased to 260 mA through an internal PMOS switch and then decreased to 0 mA through an internal NMOS switch. In this way, the energy is efficiently supplied to the output capacitor. It is worthwhile to note that this hysteretic method reduces losses associated with FET switching and holds low the output loads. In fact, in the switching process, the buck converter provides at least 100 mA of average load current. The circuit that manages the output AC current from the piezoelectric transducer [41] is graphically represented in Figure 9 b. The AC standard is the simplest form of power conditioning and directly connects a resistive load between the two electrodes of the considered transducer. Whereas, the DC standard rectifies the output transducer, through a full bridge diode rectifier, and connects a resistive load in parallel with a storage capacitor at the output of the rectifier.

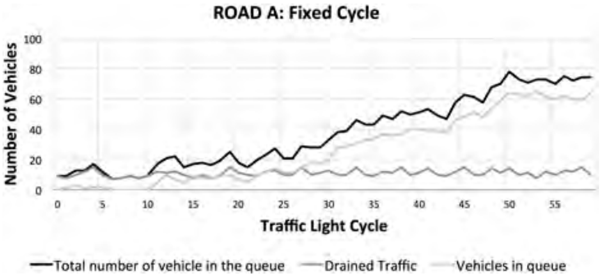

Figure 10: Road A: values obtained with a fixed traffic light cycle

4 Performance Evaluation

4.1 Dynamic traffic light manager evaluation

A generic crossroads, shown in Figure 1, has been chosen as test-bed scenario in order to evaluate our approach. Several simulations have been carried out

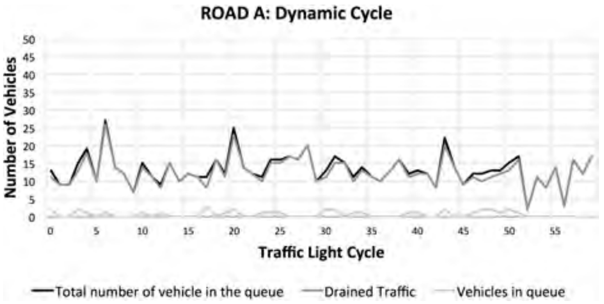

Figure 11: Road A: values obtained with a dynamic traffic light cycle

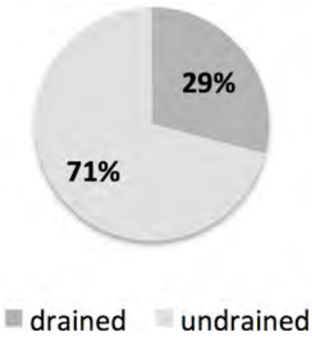

Figure 12: Road A: managed vehicles with fixed traffic light cycle

considering both a fixed-cycle traffic light and the approach proposed in this work. Regarding to traffic intensity, we considered up to 70 vehicles on each road for each traffic light. Up to 140 vehicles can be measured on each road. In both simulation cases, the reference cycle was 60 seconds and measurements have been gathered for 1 hour. Approximately, durations of fixed traffic light cycles are:

- Minimum duration: 30 seconds;
- Normal duration: 50 - 75 seconds;
- Maximum duration: 90 - 120 seconds.

The number of vehicles measured and drained in Road A, in case of fixed and dynamic cycle, are shown in Figure 10, 11, 12 and 13 respectively, while Figure 14, 15, 16 and 17 show values obtained in Road B. As shown in Figure 10, the queue it is not correctly drained in case of fixed cycle. An average value of 10.95 vehicle/minute is drained compared to an average value of 37.73 vehicles/minute measured near the traffic light. In this case 29.02% of the arrived vehicles has been drained (Figure 12). On the contrary, in Figure 11 and 13 is clearly shown that approximately 95.44% of the total number of vehicles is drained. In Figure 14 values measured in Road B using a fixed cycle are shown. In this case an average value of 31.50 vehicles/minute has been detected

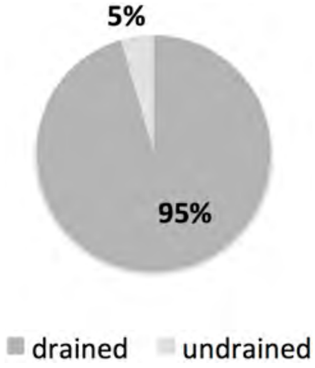

Figure 13: Road A: managed vehicles with dynamic traffic light cycle

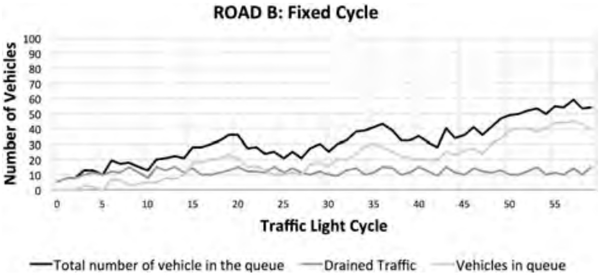

Figure 14: Road B: values obtained with a fixed traffic light cycle

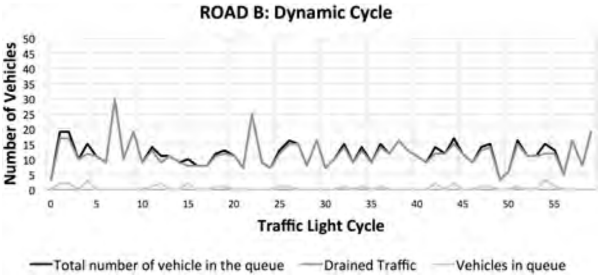

Figure 15: Road B: values obtained with a dynamic traffic light cycle

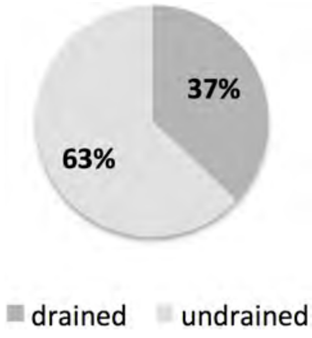

Figure 16: Road B: managed vehicles with fixed traffic light cycle

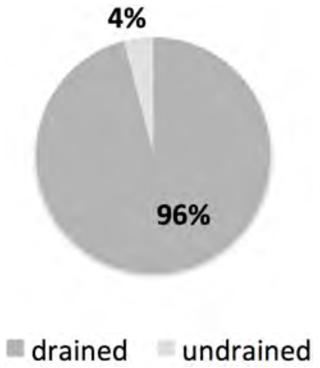

Figure 17: Road B: managed vehicles with dynamic traffic light cycle

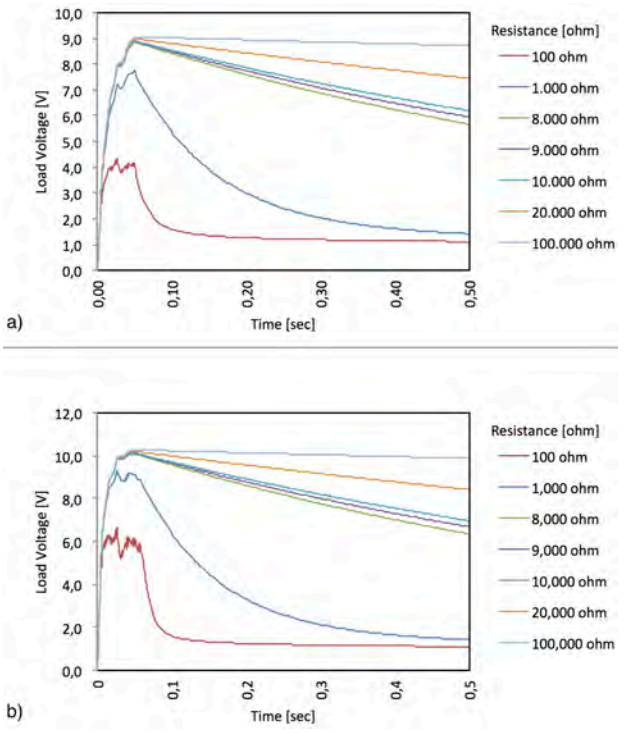

Figure 18: Load Voltage vs Time plotting for different resistance R2 values: a) Serial configuration; b) Parallel configuration

but of these just an average value of 11.67 has been drained. Therefore approximately 37.04% of the arrived vehicles has been drained (Figure 16). As shown in Figure 15 and 17, using our approach about 95.91% of total arrived vehicles has been drained.

4.2 Piezoelectric device evaluation

In this section, simulation results related to the piezoelectric device for Bluetooth sensors charge are shown. In order to evaluate the response variation, both in terms of electric potential and electric power generated by electromechanical coupling, two different simulations have been carried out. The analysis has been conducted through the development of some 3D numerical models using the FEM code COMSOL MULTIPHYSICS 4.2 [42] and QUCS 0.0.16 for the electromechanic coupling and the simulation respectively. The FEM model consists of a free tetrahedric mesh made by 14.658 solid elements (90.514 degree of freedom). Firstly, a static analysis was made by applying a displacement imposed to the upper surface of the box, of 10 mm (Figure 8). Then, two dynamical studies with and without the circuit respectively were made. Two different piezo polarization configurations [43] have been used in order to perform the numerical simulation. The main aim of this choice is to evaluate how the response of the model changes by changing the polarization direction and resistive load applied [35]. Simulation results show how the increasing of the R2 resistance value (from 100 ohm to 20.000 ohm) produces a more stable load voltage over the time, both for the serial and the parallel configuration (Figure 18). More in detail, as shown in Figure 18 (a) and (b) respectively, in the serial configuration the load voltage varies from 0,0 V to 10,0 V while in the parallel configuration values varies from 0,0 V to 6,0 V. As shown in Figure 19, it is clear how the serial configuration produces little better performance than the parallel configuration by comparing the peak voltages measured using the serial (see Table 1) and parallel (see Table 2) polarization respectively.

Table 1: Serial configuration: average voltage and power harvested from the system vs. load resistance

R load (Ω)	Vm (V)	P (mW)
1,00E+02	0,25	0,65
1,00E+03	2,20	4,84
8,00E+03	5,80	4,21
9,00E+03	6,01	4,01
1,00E+04	6,20	3,84
2,00E+04	7,03	2,47

5 Conclusions

Bluetooth networks are used in several applications for their useful features. The possibility to use real-time information in order to dynamically manage the traffic light cycles is a key aspect of ITS applications. However, Bluetooth sensor devices are battery powered, whereby batteries must be replaced after their normal duration (dependent on the use). In order to reduce queues at traffic lights, in this paper a novel

Table 2: Parallel configuration: average voltage and power harvested from the system vs. load resistance

R load (Ω)	Vm (V)	P (mW)
1,00E+02	0,35	1,13
1,00E+03	2,25	5,06
8,00E+03	4,49	2,52
9,00E+03	4,66	2,33
1,00E+04	5,05	2,17
2,00E+04	5,45	1,28

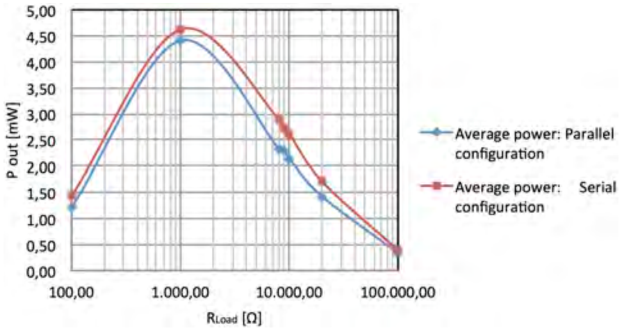

Figure 19: Comparison between the average electrical power harvested from the system depending from the load Resistance

methodology for intelligent traffic light junction management has been presented. The proposed approach is based on real time information provided by a Bluetooth sensor network powered by energy harvesting devices inserted within a road cavity in order to catch the external vibrations, caused by the passage of vehicles. Several simulations have been carried out and obtained results are very promising both in terms of queues management and in terms of the proposed energy harvesting technique. The obtained positive results lead to further detailed experimental analysis.

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