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Warim: Wireless sensor network Architecture for a Reliable Intersection Monitoring

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A traffic light controller takes as input an estimation of the number of vehicles entering the intersection and produces as output a light plan, with the objective to reduce the traffic jam. The quality of the input traffic estimation is a key consideration on the performance of the traffic light controller. The advent of Wireless Sensor Networks, with their relatively low deployment and operation price, led to the development of several sensor-based architectures for intersection monitoring. We show in this paper that the solutions proposed in the literature are unrealistic in terms of communication possibilities and that they do not allow a measure of the vehicular queue length at a lane level. Based on extensive experimental results, we propose an energy efficient, low cost and lightweight multi-hop wireless sensor network architecture to measure with a good accuracy the vehicle queue length, in order to have a more precise vision of traffic at the intersection. Associated challenges are then discussed, such as self-configuration, routing and energy harvesting, which should be addressed in order to reduce the cost of the proposed solution and to improve the performance of the target application.

Keywords: Sensing, Vision, and Perception; Communications and Protocols in ITS; Road Traffic Control

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1 Introduction

The concept of Intelligent Transportation Systems (ITS) refers to the introduction of intelligence in the transport sector by using Information and Communication Technologies (ICT), in order to deliver more innovative services both in terms of user safety and economics. Services offered by ITS are numerous ; they include vehicle count, tunnel and bridge infrastructure monitoring, collision avoidance, drivers guidance, electronic tolls, traffic monitoring and traffic lights management [1, 2, 3]. Intelligently managing the traffic lights could reduce traffic congestion in urban areas, producing a significant economic impact for countries adopting this ITS technology. Indeed, an adaptive and smart management of traffic lights is expected to reduce travel times, stopping at intersections, environmental impact of vehicles and fuel consumption.

In the case of an intelligent traffic light control application, an ideal controller takes as input the number of vehicles on each lane and their respective waiting time, and produces as output the light plans for each direction. As a matter of fact, a traffic light management system can be divided into two main components : the vehicular traffic monitor and the traffic light controller. The first component monitors vehicular traffic at the intersection and provides data, i.e. per-lane vehicle queue length, to the second component, which implements a traffic light management algorithm. Recent research mostly focused on the traffic light management part, numerous such algorithms being proposed in the literature [5, 4, 6], while the traffic monitoring problem has been somehow neglected. In this paper, we focus on vehicular traffic monitoring, and more precisely on the measure of the vehicle queue length on each lane of an intersection. We believe that the monitoring system is very important, as the quality of the input can highly impact the scheduling performance. The different controller algorithms, which try to reduce waiting time at each intersection and overall driving time by an optimal scheduling of the green lights, usually make the assumption of a perfect monitoring system, which is difficult to achieve in reality. An important research challenge, addressed in this paper, can then be formulated as : is there a way to reliably and accurately monitor vehicular traffic at an intersection ?

In ITS traffic monitoring applications, vehicle detectors are deployed, and most of the offered services depend on the accuracy of gathered data. The accuracy in this context refers to the difference between the data provided to the target application and the ground truth. The closer the reported data is to the ground truth, the higher the accuracy. For traffic light management applications, for example, the accuracy of the controller input (the vehicle queue length) represents how close the measured data is to the real vehicle queue length on the road.

With the advent of Wireless Sensor Networks (WSN) and their low equipment, installation and maintenance costs, several WSN-based architectures have been proposed for road and intersection monitoring [5, 7, 6]. In these solutions, magnetometer sensors are used for vehicle detection, and standardized technologies such as IEEE 802.15.4 [8] are used for sensor-to-sensor communications in order to allow the data collection. Nevertheless, most of these proposed solutions focus on the light planning algorithm, and do not take into account wireless network properties and application requirements. Indeed, unstable radio links due to environment perturbation, non line-of-sight conditions and obstacles, or the accuracy of the vehicle queue length measurement are not considered in these solutions. We argue that these approaches are impractical in terms of wireless network communication, and they remain inaccurate in terms of the quality of data reported, which represents a major obstacle for their deployment.

In this paper, based on several extensive test campaigns, we propose a WSN architecture for intersection traffic monitoring. Compared to previous approaches, the proposed solution is realistic from a network communication point of view, can measure traffic flow with a better precision and is cost competitive. Our contribution is threefold :

- We provide experimental results, showing that previous solutions proposed in the literature can not be supported by a WSN approach for vehicular monitoring ;
- We propose WARIM a novel Wireless sensor network Architecture for Reliable Intersection Monitoring, allowing reliable data collection, and providing accurate per-lane vehicular queue length estimation ;
- We discuss important challenges that should be addressed on the network side to reduce the overall financial cost of the proposed system, with a special focus on energy harvesting, self-configuration and routing protocols.

The remainder of this paper is organized as follow. In Section 2, we present WSN architectures proposed in the literature for intersection monitoring. In Section 3, starting from field tests, we show the limits of previous approaches, and we propose our solution. Research challenges concerning this novel architecture are discussed in Section 4. We conclude our work and present perspectives in Section 5.

2 Existing Solutions

In this section, we discuss the most significant WSN architectures proposed in the literature for data collection with an intersection management purpose. We classify these solutions into two categories : detector-based architectures and link-quality-based architectures. In detector-based architectures, dedicated types of sensors, e.g. magnetic sensors, are used to detect vehicles at a given location of the intersection [5, 7, 6]. In the second approach [9, 10], only radio units are deployed, and traffic flows at the intersection are estimated based on the properties of the radio link between these devices.

2.1 Detector-based solutions

Most of the proposed solutions for intersection monitoring are based on single vehicle detection. Detection technologies can be classified as in-roadway sensors and over-roadway sensors [11]. An in-roadway sensor is one that is either embedded in the pavement of the roadway, embedded in the subgrade of the roadway, or taped or otherwise attached to the surface of the roadway. Pneumatic road tubes, inductive loop detectors, magnetic sensors, piezoelectric sensors and weigh-in-motion are some examples of in-roadway sensors. An over-roadway sensor is one that is mounted above the surface of the roadway, either above the roadway itself, or alongside the roadway, offset from the nearest traffic lane by some distance. Video image processors, microwave radars, infrared sensors, ultrasonic sensors and passive acoustic array sensors are some examples of over-roadway sensors. The main and most visible difference between in-roadway and over-roadway sensors is that the latter can be deployed without disturbing traffic. However, regarding the sensor financial cost, the most deployed over-roadway sensors, video cameras, are much more expensive compared to magnetic sensors, which are the most popular in-roadway solution [11]. Apart from the cost, the specific placement required alongside the roadway, usually on lampposts, is another strong constraint of over-roadway detectors.

Detector-based architectures can be further classified into two categories : infrastructure-free and infrastructure-based.

2.1.1 Infrastructure-free architectures

In most of the architectures proposed in the literature [5, 7, 6], magnetic sensors are the main detection technology used for traffic light control applications. With this solution, nodes equipped with 2 or 3-axis magnetometers are deployed on the road to detect the presence or passing of vehicles. Based on the IEEE 802.15.4 standard, which theoretically provides a communication range in the order of 70-100m, this kind of architecture is adopted by most of the researchers (see Fig. 1). In this architecture, two sensors are used per lane : Arrival Detector (AD) sensor, which is used to detect the arrival of a vehicle at the intersection and Departure Detector (DD) sensor, which is used to detect vehicles exiting the intersection. When a vehicle is detected by AD sensor, a message is send to DD sensor. Then DD sensor uses arrival and departure information to compute the number of vehicles per lane. This architecture has several drawbacks which directly impact the performance of the traffic light controller. The first drawback is the low precision on the number of vehicle reports per lane. Indeed, once a vehicle has been detected by the AD sensor, nothing prevents it to change lanes, especially given the large distance (up to 100m) between the two sensors. A second drawback with this architecture is represented by the *unauthorized* stops at the intersection. Indeed, if after passing above the AD sensors, a vehicle stops for technical or human reasons, it is not possible with

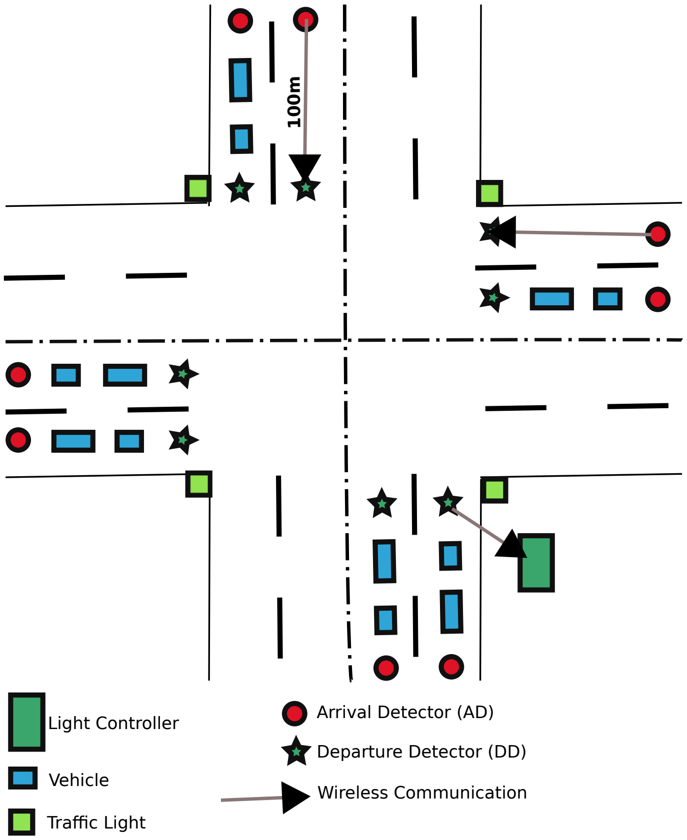

FIGURE 1: Infrastructure-free WSN architecture for traffic light control

this architecture to automatically and quickly detect or localize this situation. The last but most important drawback with this kind of architecture is to guarantee a reliable wireless communication using the IEEE 802.15.4 standard between two sensors placed over or under the roadway and at a distance of 100m. Experimental results, presented in the next section, prove that such a communication range is not achievable in such environment.

2.1.2 Infrastructure-based architectures

To deal with this communication issue, the use of an infrastructure deployed along the road was proposed [12]. In this example, in order to allow line-of-sight conditions favorable to radio communication, at least one wireless node is not located at the road level but higher above the ground to collect data : reliability is improved and a longer radio range is achieved. Therefore, in such solutions, repeaters are installed along the road, at a given height, to relay messages coming from the monitoring sensors. AD and DD sensors, located at ground level, report messages to the repeaters, which relay received packets to the controller. Even if the radio communication issue is well-addressed by this kind of architecture, all the other problems mentioned for infrastructure-free architectures remain. Note that such an architecture also leads to an increased financial cost, as additional infrastructure has to be purchased, deployed and maintained, which can significantly increase the cost of the system.

2.2 Link-Quality based solution

In the previously discussed approaches, vehicles are detected using either in-roadway or over-roadway sensors, and repeaters along the roadside can be used to improve the reliability of the data collection to the controller. In [9, 10], authors proposed a WSN architecture for traffic estimation based on the monitoring of the quality of radio links, where no dedicated monitoring sensors are used (see Fig. 2). The main idea of this solution is that vehicle flow influences the radio link quality between transmitter (TX) and its associated receiver (RX). Both are installed on the two sides of the road at a height of 0.5m. Received Signal Strength Indicator (RSSI) measured between TX and RX node is used to classify traffic condition as free flow or congested based on a threshold.

Unfortunately, this architecture allows only to give a general view of the traffic conditions on each road of the intersection without any detail of the number of vehicles per lane. This implies that the system cannot be used in a situation where a high accuracy on the number of vehicles is required or when intersection monitoring is integrated in a global traffic management at a city scale. Moreover, both arriving and leaving vehicles impact the radio link quality ; this leads to overestimate the traffic condition because both arriving and leaving vehicles are counted together, while only arriving vehicles should be taken into account in traffic light management. If this solution does not disrupt traffic flow during deployment, the installation of transmitter and receiver nodes increases significantly the financial cost.

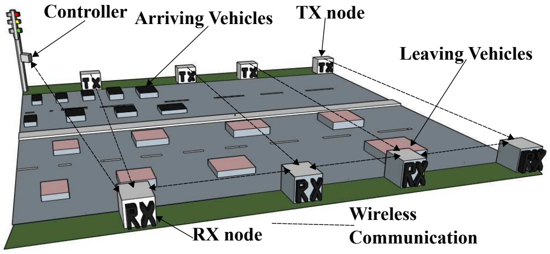

FIGURE 2: Link-Quality based architecture for traffic light control

3 WARIM : Wireless sensor network Architecture for a Reliable Intersection Monitoring

Our goal is to propose an energy efficient, low cost and lightweight WSN solution to accurately estimate the vehicle queue lengths at an intersection. To overcome the problems previously highlighted, we propose, building on experimental results, a new WSN architecture for vehicle count and queue length estimation for traffic light control.

3.1 Problem statement

As discussed above, an adaptive traffic light control application requires vehicular flow information, collected at the intersection level. The performance of the light scheduling algorithm depends on the accuracy of the collected data : the reliability of the vehicle queue length estimation can have a significant impact on the quality of the scheduling. As mentioned in the previous section, and for all related works, three drawbacks can negatively impact the target application : *i)* the low accuracy of vehicle queue length estimation at a lane level, *ii)* the incapacity to detect and localize *unauthorized* stops around the intersection, and *iii)* the unreliable nature of the radio links of the network which implies non reliable data gathering from the monitoring sensors. Moreover, the financial cost and the network lifetime, which is determined by the nodes' energy consumption, are not taken into account.

We propose WARIM (*Wireless sensor network Architecture for a Reliable Intersection Monitoring*), a lightweight WSN architecture for intersection monitoring. Our initial motivation is to provide a solution with a reasonable financial cost in order to be accessible to most municipalities, especially in emerging countries. This leads us to consider low cost technologies, such as an open standard communication protocols (*e.g.* IEEE 802.15.4). Moreover, to reduce deployment and maintenance costs, we have to limit the human intervention, thus self-configuration and self-organization protocols must be developed. WARIM should also exhibit a long lifetime, thus the energy is a main concern : we propose to use classical battery-equipped wireless sensor nodes but having also energy harvesting capabilities [15]. Finally, to reduce deployment time and road deterioration, surface-mounted sensors should be used. This raises an important challenge from the networking point of view, as communication between devices at ground level is characterized by a high degree of unreliability.

3.2 Experimental results

Related monitoring architectures assume unrealistic radio link properties, mainly in terms of stability, connectivity and reliability : our experimental results show that such assumptions are never met, leading to nonfunctional architectures for a real deployment. To characterize the radio link, we measure the packet reception ratio as a function of distance between two nodes in case of presence or absence of vehicle. We also evaluate the maximum distance between 2 nodes that allows a reliable communication.

3.2.1 Experiments setup

We use two IEEE 802.15.4 CROSSBOW TelosB sensor nodes [†] (denoted as **A** and **B**), deployed on the road surface. In the following, $A \to B$ denotes the communication from node **A** to node **B** and $B \to A$ from node **B** to node **A**. We consider a transmission power of 0dBm, which is the highest allowed by these nodes. An extensive set of experiments was conducted, but, due to format constraints, only two scenarios are described here :

- **Experiment 1 :** Sensors **A** and **B** are deployed on the road surface without any vehicular traffic.
- **Experiment 2 :** A vehicle is deployed above the sensor **A** (see Fig. 3). The vehicle used in this experiment has a length of 4m.

The distance d between the two sensors varies from 1m to 30m (Experiment 1) and from 3m to 20m (Experiment 2) with a step of 1m. Each time, 200 packets were transmitted by the two nodes, allowing us to measure the packet reception ratio (PRR) on links $A \to B$ and $B \to A$.

3.2.2 PRR as a function of distance - Experiment 1

Fig. 4 presents the packet reception ratio as a function of d for the first experiment. Contrary to theoretical results, the PRR is not a strictly decreasing function of distance. In Experiment 1, results show that the PRR is higher at a distance of 9m-12m (PRR > 0.75) compared to a distance of 5m or 8m (PRR < 0.3). Such results are obtained considering a reasonable confidence interval due to the 200 transmissions which are

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[†] http ://www.willow.co.uk/TelosB_Datasheet.pdf

FIGURE 3: Deployement area

processed. While the precise shape of the results is very likely due to the characteristics of each deployment area we considered (such as the road topology or the presence of sources of electromagnetic interference), a similar trend, but with different quantitative results, can be noticed in all the delployment areas we study. These results illustrate that communication between devices at road level is possible, but remains unreliable and unpredictable.

Moreover, we can note that the PRR is very low for distances beyond 15 meters, with a reception probability lower than 1%. It means that it is not reasonable to consider a reliable radio link between two nodes separated by more than 15m. This shows that previous monitoring solutions (see Section 2), which propose sensors separated by up to 100m, can not work in a practical deployment.

Finally, Experiment 1 allows us to illustrate the asymmetric nature of radio links between the nodes. Indeed, the results show that, at given distances, the PRR is not the same in both communication directions. For example, at $d = 8m$, the PRR is close to 0.9 for $B \rightarrow A$, while it is less than 0.15 for $A \rightarrow B$. After investigations on the deployment area, we conclude that these results are produced by a bump on the road surface, which results in node **B** being placed slightly higher than node **A**. These situations are very likely in real deployments, and such considerations should be taken into account in the design of communication protocols. It also means that the environment has a strong impact on the radio link properties.

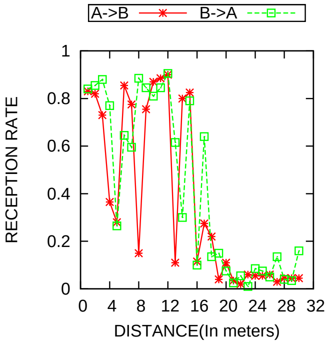

FIGURE 4: PRR as a function of distance (Experiment 1)

3.2.3 PRR as a function of distance - Experiment 2

The effect of deploying a vehicle on sensor **A** can be observed in Fig. 5, which shows that the presence of a vehicle highly impacts the communication between the two nodes. Indeed, the PRR is less than 0.2 much of the time, except at 9m where we observe a peak in both communication senses. In such conditions, with a low PRR, retransmissions should be used to improve the communication reliability, while opportunistic forwarding can reduce the delay needed to gather data from the monitoring sensors. Unfortunately, it means that the presence of vehicles degrades the connectivity between nodes, even if sometimes the waveguide effect is present.

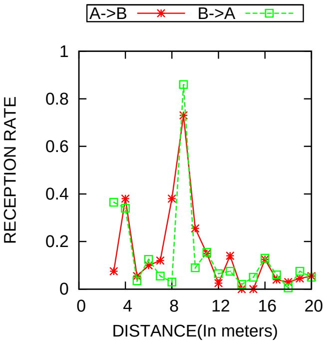

Figure 5: PRR as a function of distance (Experiment 2)

3.3 Proposed architecture

Based on these experimental results, we propose an architecture where sensors are deployed on the road surface, and they are able to communicate through a multi-hop WSN to report vehicle detection to the controller. In our proposition, Warim (Fig. 6), several sensors are deployed on each lane of the intersection, and the distance between two sensors on a given lane is in the order of 5-10m, which is smaller than the one proposed in related works. This short distance allows us to achieve two important goals. Firstly, communication between nodes is now reliable, even in the presence of vehicular traffic. If the radio links remain asymmetric, unstable and dynamic because of the environment, the short distance we recommend leads to better connectivity. Nevertheless, additive mechanisms such as retransmissions and coding scheme are still required to optimize the networking operations. Secondly, the dense deployment proposed in Warim achieves a more accurate per-lane estimation. By using a small distance between sensors, Warim provides an accurate measure of the vehicle queue length at lane-level, optimizing the functioning of the traffic light control algorithm.

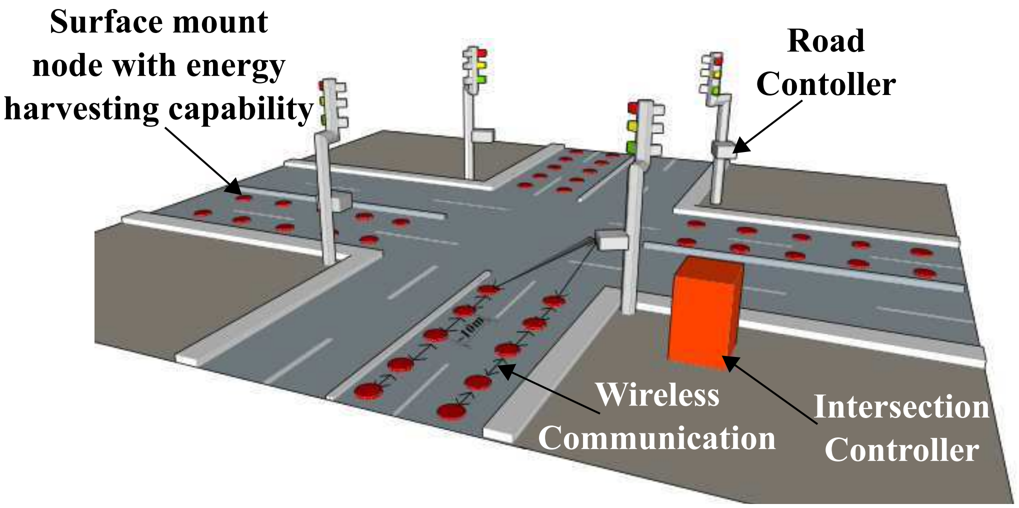

Figure 6: Warim : Wireless sensor network Architecture for a Reliable Intersection Monitoring

The number of sensors deployed on each lane depends on the desired accuracy and the node communication capabilities. The higher the number of deployed sensors, the better the accuracy, but a dense deployment also increases the financial cost of the monitoring system. This trade-off needs to be well understood before the deployment phase. The only requirement imposed by WARIM is that the deployment of the sensor nodes results in a connected network, which produces a certain level of accuracy. If higher accuracy is required, a denser deployment should be used. WARIM uses only surface-mounted sensors without extra infrastructure, therefore highly reducing the deployment and maintenance costs. Moreover, the sensors are equipped with energy harvesting capabilities, further reducing the maintenance time, as solar energy harvested by small size panels will be used, instead of human intervention, to recharge the nodes' batteries.

4 Remaining challenges

As mentioned above, WARIM is designed with the characteristics of ground level wireless links in mind, but it still has to tackle some important challenges in order to optimize networking operations. Moreover, it is essential to propose a low cost solution, so we need to develop an autonomous system both in terms of energy requirements and communication protocols, minimizing human intervention, which dominates the costs related to the deployment and operation of wireless sensor networks.

4.1 Energy Harvesting

Generally speaking, wireless sensor nodes are battery-powered. When the battery is exhausted, it can be replaced if the deployment area is accessible. In WARIM, to reduce the maintenance cost, sensor nodes take benefit from renewable energy sources. Recently, with the evolution of energy harvesting technologies, and particularly solar energy, small size solar cells have been proposed for WSN [14, 15].

Energy-aware networking protocols are generally used in battery-powered WSN to manage efficiently the energy consumption of nodes. In energy harvesting WSN, the network lifetime is theoretically infinite, and it is only limited by hardware lifetime. Then, the main considerations regarding energy should be *i)* to schedule the data transmission according to the energy available and to anticipate the energy depletion using a data traffic schedule, *ii)* to maximize throughput and *iii)* to guarantee perpetual network functioning, i.e. allow the network to function even in the lack of harvesting sources for a long time. The energy produced by a solar panel depends on its size, the season, the period of the day, the area where the panel is deployed and the availability of sunshine radiation. In the case of WARIM, because vehicles stop at the intersection when the light is red, sensors close to the traffic light are shadowed much of the time by vehicles and harvest less energy compared to those which are far. Moreover, such sensors have to relay control packets sent by other nodes. Clearly, this means that the power consumption of such nodes has to be studied finely, by taking into account data traffic intensity and the available energy sources. Transmission scheduling, topology management, and dynamic routing protocols should be designed by considering renewable energy cycles.

4.2 Self-Configuration

Network deployment and configuration is one of the activities that increase the cost of WSN. In order to reduce deployment and configuration time, self-configuration protocols for different WSN applications are proposed in the literature [13]. A configuration parameter of a sensor node for traffic monitoring can be its *location* : in WARIM, the location can be defined as the lane on which the node is deployed and its relative position with respect to the light controller. Nodes' locations are very important both for network and application purposes. In the network, they can be used for neighborhood setup and exploited by the routing protocol for data report. In the case of the traffic light control application, the location of the sensor node is used to know exactly the position of a detected vehicle. The configuration problem here is the construction of the physical topology of the deployed nodes at a network level.

A simple solution to solve this problem is to manually configure each node, as it is currently done by manufacturers[‡]. This solution not only increases the financial cost of the system in terms of deployment time, but it also requires the participation of specifically trained human resources. Another solution is to equip each node with a localization device (*e.g.* GPS). However, this solution not only increases the financial cost of the nodes, but also consumes a significant amount of energy. Moreover, the problem here is not to

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[‡] http ://www.hikob.com, http ://www.sensysnetworks.com/

self-calculate the precise distance between nodes, but to simply localize each node on the road. An important challenge for WARIM should therefore be to develop communication protocols that can allow the network to self-organize and self-configure. These protocols should take into account the specific properties of radio links in a vehicular environment.

4.3 Routing

Due to energy constraints and due to the environment, the communication range of wireless sensor nodes is generally limited. As shown in Sec. 3.2.1, this is particularly true in vehicular traffic monitoring. To send data to the controller, a multi-hop approach is required, which makes routing a key service for each node in the network. Numerous routing protocols have been proposed in the literature for WSN [16]. For energy-efficient routing protocols, battery level of nodes and topology control are generally used for routing decisions. Routing protocols for energy harvesting WSN must take into account not only the battery level of nodes but also the harvested capacity of each node in the network. For example, Kansal et al. [14] propose to combine the residual battery level and the expected rate of energy harvesting in order to select routes in the network.

In the case of an intersection monitoring system, the distribution of vehicular traffic on different lanes is not uniform. In a given direction, with multiple lanes, it is possible to have some lanes with a very high vehicular traffic compared to other. Moreover, nodes close to the controller must contribute more than others to the network communication task, because they should generate their own data, but also forward data coming from others nodes. This implies that these nodes require more energy and, as we have mentioned in the Section 4.1, they are also the ones having less energy harvesting capabilities. Then, a reliable routing protocol for WARIM must *i)* take into account the energy potential of each node (its battery level and energy harvesting capabilities), *ii)* balance network traffic load on nodes deployed on different lanes, *iii)* take benefit from opportunistic radio links, and *iv)* exploit the particular topology of our architecture.

5 Conclusion

In this paper, we deal with vehicle traffic monitoring at road intersections. We argue that WSN architectures proposed in the literature are inaccurate in terms of the vehicle queue length estimation, and are not suitable for network communication because of the wireless topologies proposed. Starting from extensive measurements in a real vehicular environment, we propose a new, energy efficient, low cost and lightweight multi-hop wireless sensor network architecture, WARIM, to accurately measure the vehicle queue length at intersection. We discuss the remaining challenges related to WARIM, including energy harvesting, self-configuration and routing. These challenges will be addressed in our ongoing and future works.

Références

[1] A. Sharma, R. Chaki, and U. Bhattacharya, “Applications of Wireless Sensor Network in Intelligent Traffic System : A Review”, In *ICECT 2011*, Kanyakumari, India, April 2011.

[2] F. Losilla, A.-J. Garcia-Sanchez, F. Garcia-Sanchez, J. Garcia-Haro, and Z. Haas, “A Comprehensive Approach to WSN-based ITS Applications : A Survey”, In *Sensors*, 11(11) : 10220–65, October 2011.

[3] F. Stajano, N. Hoult, I. Wassell, P. Bennett, C. Middleton, and K. Soga, “Smart Bridges, Smart Tunnels : Transforming Wireless Sensor Networks from Research Prototypes into Robust Engineering Infrastructure”, In *Ad-Hoc Networks*, 8(8) : 872–888, November 2010.

[4] P. Mirchandani, and L. Head, “A Real-Time Traffic Signal Control System : Architecture, Algorithms, and Analysis”, In *Transportation Research Part C : Emerging Technologies*, 9(6) : 415–432, December 2001.

[5] S. Faye, C. Chaudet, and I. Demeure, “A Distributed Algorithm for Single Intersections Adaptive Traffic Lights Control using a Wireless Sensor Networks”, In *IEEE ITSC 2012*, Anchorage, AK, USA, September 2012.

[6] B. Zhou, J. Cao, X. Zeng, and H. Wu, "Adaptive Traffic Light Control in Wireless Sensor Network-Based Intelligent Transportation System", In *IEEE VTC Fall 2010*, Ottawa, ON, Canada, September 2010.

[7] M. Tubaishat, Q. Qi, Y. Shang, and H. Shi, "Wireless Sensor-based Traffic Light Control", In *IEEE CCNC 2008*, Las Vegas, NV, USA, January 2008.

[8] Institute of Electrical and Electronics Engineers, "IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks Specific Requirements Part 15.4 : Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)", 1–670, October 2003.

[9] S. Roy, R. Sen, S. Kulkarni, P. Kulkarni, B. Raman, and L.K. Singh, "Wireless Across Road : RF based Road Traffic Congestion Detection", In *COMSNETS 2011*, Bangalore, India, January 2011.

[10] R. Sen, A. Maurya, B. Raman, R. Mehta. R. Kalyanaraman, N. Vankadhara, S. Roy, and P. Sharma, "Kyun Queue : A Sensor Network System to Monitor Road Traffic Queues", In *ACM SenSys 2012*, Toronto, ON, Canada, November 2012.

[11] L. Mimbela, L. Klein, P. Kent, J. Hamrick, K. Luces, and S. Herrera, "Summary of Vehicle Detection and Surveillance Technologies Used in Intelligent Transportation Systems", In *Federal Highway Administration's Intelligent Transportation Systems Program Office*, August 2007.

[12] C. Day, H. Premachandra, T. Brennan, J. Sturdevant, and D. Bullock, "Operational Evaluation of Wireless Magnetometer Vehicle Detectors at Signalized Intersection", In *Transportation Research Record : Journal of the Transportation Research Board*, 2192(1) : 11–23, February 2010.

[13] K. L. Mills, "A Brief Survey of Self-organization in Wireless Sensor Networks : Research Articles", In *IEEE Wireless Communication Communications & Mobile Computing*, 7(7) : 823–834, September 2007.

[14] A. Kansal, J. Hsu, M.B. Srivastava, and V. Raghunathan, "Harvesting Aware Power Management for Sensor Networks", In *ACM/IEEE DAC 2006*, San Francisco, CA, USA, July 2006.

[15] S. Sudevalayam, and P. Kulkarni, "Energy Harvesting Sensor Nodes : Survey and Implications", In *IEEE Communications Surveys & Tutorials*, 13(3) : 443–461, September 2011.

[16] J.N.Al-Karaki, and A.E. Kamal, "Routing techniques in wireless sensor networks : a survey“, In *IEEE Wireless Communications*, 6(1) : 6-28, December 2004