WVSN: Towards Merging Vehicular Ad hoc Networks and Wireless Sensor Networks *

Djamel Djenouri

CERIST Research Center
Rue des 3 frères Aïssou Ben-Aknoun, Alger, Algérie

ddjenouri@cerist.dz

Résumé : Le système documentaire algérien est marqué par l'absence d'un dispositif scientifique d'envergure national permettant le contrôle et l'évaluation du mode de fonctionnement des bibliothèques. D'autant plus que celles-ci souffrent de nombreuses difficultés, notamment, l'insuffisance des moyens, l'absence d'une législation adaptée aux exigences des bibliothèques, l'absence d'un plan national de formation du personnel, etc. Ces contraintes entravent la relance et le développement des bibliothèques non seulement sur le plan organisationnel et humain mais aussi sur le plan de la maîtrise des TIC. De ces faits, la création d'un Observatoire du système documentaire national est la résultante de la volonté affirmée d'avoir l'état actuel des bibliothèques en Algérie pour la mise en œuvre d'un schéma directeur de développement du système national d'information. Dans ce cadre, un modèle d'organisation pour l'Observatoire est proposé et un ensemble d'outils méthodologiques et pratiques sont développés.

Abstract: This paper reviews current applications based on Wireless Vehicular Sensor Networking (WVSN); an emerg- ing type of wireless and mobile networks that combines wireless sensor networks (WSN) and vehicular ad hoc networks (VANET). Some recent researches have been devoted to proposing new solutions for several vehicular applications using networked wireless sensors, but an up-to-date state-of-the-art paper of these works is missing. To our knowledge, this manuscript is the first that provides a comprehensive survey discussing the potential civilian applications of WVSN, the solutions proposed thus far, and the remaining challenges. According to the application domain, solution are split into: i) safety applications, ii) traffic management and vehicle tracking, iii) environment and urban monitoring. State-of-the art solutions using networked wireless sensors, and involving car-to-car and/or car to roadside communications are reviewed for each category. Current commercial solutions using wired sensors or individual sensors are out of the motivation of this survey..

Mots clés : Réseaux de capteurs sans fil, Réseaux ad hoc véhiculaire, Réseaux mobile et applications.

Keywords: Vehicular ad hoc networks, wireless sensor networks, mobile networks and applications.

* WVSN: Vers la Fusion des Réseaux Ad hoc Véhiculaire et les Réseaux de Capteurs Sans Fil

1. Introduction

Mobile Ad hoc networking (MANET) is a general concept that includes many kind of networks, all characterized by the independency from any fixed infrastructure, self-organization, dynamic topology, and adaptability. Amongst the concrete kinds of MANET we find wireless sensor network (WSN), which consists of a set of tiny sensor motes interconnected in ad hoc way through wireless channels. WSN's nodes are limited in resources such as energy, storage, and computation. These limitations represent the main challenge that faces the concretization of WSNs in a large scale. There are many possible applications of these networks, ranging from military applications, to environment and infrastructure monitoring, to medical applications, etc. Vehicular ad hoc networking (VANET) represents another type of ad hoc networking. Contrary to WSN, a VANET is generally not constrained to the limitations in resources as it consists in connecting *computers* embedded in vehicles instead of tiny sensor motes, which are relatively more powerful (in computation and storage) and can take advantage of the high energy resource (vehicle's battery). However, VANET are basically featured by the high mobility of nodes forming the network, in contrast to WSN where nodes are usually stationary. Further, unlike the traditional vehicular networks that rely on dedicated infrastructures or existing cellular systems [1], communications in VANET between vehicles are direct, without depending on any fixed points. This facilitates the deployment of the network but introduces many challenges that should be tackled [2].

Merging the two technologies (WSN and VANET) results in wireless vehicular sensor networks (WVSN), a very attractive research trend nowadays. A WVSN can be defined as the use of networked wireless sensors for the vehicular application. These sensors can be embedded in vehicles, or dispersed in roadside and connected with each other to disperse the sensed data. They are cooperate to providing the required services. The service to provide differs from an application to another. For instance, in a safety application it may consist in alerting the driver to an accident beyond his line of sight, or any potential dangerous situation such that to prevent a collision. On the other hand, in vehicular traffic management and re-routing, it may consist in informing the driver of the current traffic concentration on possible routes for his journey. This technology will definitely enhance the usefulness of the existing intelligent vehicular systems, and will particulary overcome the lack of infrastructure in rural and suburban areas. In recent years, some projects have been devoted to such kind of networks. This survey provides an overview on these works. It enumerate the possible applications of WVSN, as well as the remaining challenges.

The remaining of the paper is organized as follows: in the next section the related work will be presented, followed

in section 3 by an investigation into the feasibility of communication between sensors in WVSN. Solutions related to the safety application will be illustrated in section 4, those related to traffic management and vehicle tracking in section 5,

Solution	Senors Placement	Communication	Transducer	Type of roads	Type of messages
Karpinski et al.	roadside	multi-hop	magnetic	2-way 1-carriageway	alerts
Sawant et al.	in-vehicle	multi-hop	mil-radar + possibly cameras	not specified	periodic+alerts
Xing et al.	roadside	multi-hop	not specified	highways	alerts
Yoo et al. (1)	in-vehicle	single-hop	no sensing	2-way 1-carriageway	request-based+ periodic
Djenouri et al.	in-vehicle	single-hop	magnetic + GPS	2-way 1-carriageway	periodic+alerts
Yoo et al. (2)	roadside	single-hop	light sensor	at intersections	periodic
Sharp et al.	roadside	multi-hop	magnetic	open space	alert-based
Lee et al.	in-vehicle	multi-hop	camera + chemical detectors	any	request-based+ periodic
Lopez et al.	both	single-hop	pollution detector	any	lacks precision

	Safety applications	Traffic management	Vehicle Tracking	Environment monitoring
Delay sensitive	high	no	low	no
Delivery ratio sensitive	high	high	high	low
Traffic	low	high	low	high
Need to use in-vehicle sensors	yes	not necessary	not necessary	yes
Need to use roadside sensors	yes	yes	yes	not necessary

Figure 1: Solutions Sumrnary

While solutions dealing with environrnent/urban monitoring will be presented section 6. Finally, section 7 concludes the paper and summarizes the research trends. Figure I is a paper road map, and a taxonomy of the solutions discussed in the rest of the paper.

2. Related work

Communication between smart vehicles now becomes a fact. Many vehicle manufacturers, governments, and telecom operators are promoting activities of research and development in this arena. For instance, in the US the FCC already approved 75 MHz of spectrum known as Dedicated Short Range Communication (DSRC) for Inter- Vehicle Communications (IVC) and Vehicle-to-Roadside Communication (VRC). Consequently, many research projects have been carried out, such as MobEyes by UCLA and university of Bologna and CarTel by MIP, to quote just few. In Japan, two DSRC standards have been adopted and the Japanese car manufacturers are working with the government on an ambitious advanced safety vehicle project. In Europe, several national and European projects have been conducted. We cote: the Fleetnet project in Germany, the CarTALK2000 EU funded project that started in August 2001, the current EU project SafeSpot, and last but note least the traffic telematic system and traffimatics BT research funded project in UK [3] [4]. These research projects involve as well the communication technology using dedicated infrastructure (which is now a reality) as the ad hoc paradigm that will enable in the near future the creation of vehicular ad hoc networks. Vehicular ad hoc networking (VANET) is one of the research trends in mobile ad hoc networking (MANET), on which many research efforts have been focusing in recent years. Authors in [2] provide a general survey of IVC, and the existing challenges to overcome before the real deployment. The discussion in that paper covered the physical and MAC layers, the routing protocol, group communication, and security. In [1] the authors discuss the usefulness of VANET to ensure the vehicular traffic safety and facilities, as well as the advantages it provides compared to the other centralized technologies. In addition to these surveys some specified applications have been proposed, such as discovery of free parking places [5]. Mobility modelling and simulation is the topic that received the most attention amongst researchers, and many models have been proposed, such as [6], [7], [8], [9], [10]. Compared to traditional models largely used to evaluate protocols in MANET such like the famous random-way-point (RWP) [11], these ones take into account real constraints a vehicle encounters during its movement, notably movement in limited routes defined by road maps instead of movement in open spaces, and the traffic control mechanisms (stop signs, traffic lights). These new models allow to get more accurate and credible results when simulating protocols. [12] is a comprehensive survey on these models, with more discussions and analysis.

Many efforts have been devoted to use several wired sensors embedded in vehicle such as [13], [14], [15]. Many advantages can be achieved through the addition of communication facilities and integration of networked sensors, capable to communicate between each other, and particularly with other sensors outside the vehicle [16]. In addition to information provided by the centralized systems, sensors embedded in vehicles and in roadside can provide realtime data. Moreover, when inter-connecting sensors to each other, the information can be rapidly propagated to provide a variety of applications in the new environment known as wireless vehicular sensor network (WVSN). Nekovee [17] provided the first survey on vehicular networks that addresses the possibility of integrating networked sensors in the applications on the top of a VANET. Lately, more works in this arena have been published like [18], [19], [20], [21], etc., illustrating the usefulness of WVSN and proposing solutions. This paper presents an up-to-date overview of these works, where the current proposals and the remaining challenges are discussed.

3. Feasibility of communication between sensors in wvsn

The feasibility of communication between sensors when embedded in vehicles needs deep investigations before passing to real applications of WVSN. A very interesting work with respect to this issue is [19], where the authors made real tests using Mica2 motes embedded in a moving car. In this experience sensors (Mica2 motes) were embedded at different part of the car, one in the trunk, another in the cupholder, and the last one within the engine. Another Mica2 was used as a base station connected to a laptop. This configuration allowed to study different interference situations. To generate traffic each sensor measured the temperature, and sent it to the base station every 0.1sec, which produces relatively a high traffic load. The authors tested the reliability of the communication by measuring the packet delivery and loss rates, during one hour of car movement. The results illustrate that the communication was feasible, and the greatest amount of data was successfully delivered. Nonetheless, the packet loss was not negligible, particularly for the packets provided from the engine sensor, as their loss ratio reached almost 10%. This is due to the high level of electromagnetic interference. Packet loss can be acceptable in some applications, but not in the ones involving realtime decisions. Generally speaking, this kind of applications does not require as high traffic as the one generated in the experience (one transmission every 0.1sec). In fact they generate traffic when a critical condition occurs rather than doing so periodically. More investigations into lower data rate situations are thus required. As multiple applications may co-exist in WVSN, the MAC protocol can play an important role to reduce the loss of critical packets by assigning priorities to packets. The most critical packets (e.g. packets of realtime safety applications) are associated with higher priority, and then may be transmitted rapidly, using higher power, and requiring acknowledgments (ACK packets). This will also help reducing their delay. Finally, communication between roadside sensors and embedded ones needs more study. The tests of [19] investigated the communication between devices in the same car. Even though the car itself was moving, sensors are relatively not mobile from one to the other. For communication between a roadside sensor and an in-car sensor the relative mobility would be very high indeed and equals the car's speed (since the roadside sensor is stationary), which inevitably affects the delivery ratio. Relative mobility would also be high for communication between sensors of different vehicles.

This was for single hop communication. Multi-hop communication is another problem that rises the need of an effective routing protocol. A variety of protocols have been proposed in WSN [22], but they do not consider sensor mobility and thus are not applicable in WVSN for communication involving in-vehicle sensors. Multi-cast is common in WVSN's applications. In [18] the authors propose an improvement of some ad hoc multi-cast routing protocols, namely ODMRP [23] and MAODV [24]. The protocols use a grey tracking approach that consists in discovering a new route as soon as the one in use is appreciated to have a link that becomes weak. The new route are the used for rerouting and replacing the weak. Some simulation results of the proposed protocol in WVSN scenarios have been provided, illustrating considerable improvement vs. ad hoc routing protocols with respect to the end-to-end delay. Routing protocol proposed in the context of mobile ad hoc networks may be useful for communication between mobile sensors in WVSN. However, the mobility would be very high in WVSN compared to general ad hoc networks, and thus these protocols may need to bee revisited. For communication between roadside sensors, WSN protocols are more appropriate. Giving the need of geographic information for vehicular applications, and consequently the availability of such information, it can be exploited by the routing protocol such as the localized WSN protocols [25]. These kind of protocols are energy efficient and more scalable. In the following the existing application solutions proposed for WVSN will be presented. Following the application domain, the existing solutions are divided into three classes: i) safety applications, ii) traffic management and vehicle tracking, and iii) environment/urban monitoring.

4. Safety applications

Road accidents cause enormous human and financial catastrophes. For instance, a study shows that in the U.S accidents cause more than 40,000 deaths, 3,000,000 injuries, and about 150 billion dollars in financial losses annually [26]. Accident analysis reveals that many accidents are caused by wrong driver decisions, owing to lack of good understanding of the surrounding traffic and environmental conditions. This is because while driving, the driver not only needs to control his vehicle but also needs to pay attention to the road conditions and movement of vehicles around him. However, none can be fully focused on the road continuously. The driver's visibility and perception are always limited no matter how much vigilant, and experimented he is.

WVSN can be used to assist the driver and provide useful information and services allowing to take the appropriate maneuver. A variety of dangerous situations may be overcome by the WVSN technology, such as frontal collision in two-way single carriageway routes, due to a vehicle's change of lane when another vehicle is approaching, rear-end collision in tunnel or because of a sharp vehicle stop, lateral collision at intersection, etc. A WVSN will increase the driver visibility and awareness of the traffic, as well as the surrounding environment. This enables to take the appropriate decision at the required time. The following examples illustrate some critical situations potential to accidents that can be prevented.

- Sudden stop: Consider two vehicles, A and B, go in the same direction and closely, figure 2 (a). Collision may happen between A and B when A stops suddenly. However, when using WVSN, dangerous events (e.g. a cow traversing the road) can be detected by a sensor of vehicle C or by a roadside sensor. The event can be propagated back to B and A, allowing comming nodes to reduce their speed smoothly and thus preventing a possible crash.
- Entry ramps: In the example of figure 2 (b), vehicles A and C cannot see each other. This may lead to a collision when A enters the motorway. A roadside sensor placed at the motorway entry that detects vehicle A approaching can propagate this information towards the appropriate vehicles like C and the back ones such that they can adjust their speed. This enables vehicle A to merge in between vehicles C and B without causing any lateral or rear-end collision.
- Bends and street corners: In figure 2 (c) driver of vehicle A wishes to overtake vehicle B. Vehicle C that is out of the light of sight of A, due to the bend, is a potential danger of a frontal collision. The same situation can occur in streets

with corners or in bad visibility conditions (night, fog, etc). The use of interconnected

- sensors equipped with GPS will allow vehicles to communicate their positions in such situations. Furthermore, roadside sensors at such points can be useful to launch a message in the appropriate direction as soon as a vehicle approaches the bend.
- Intersections: In the example illustrated by figure 2 (d), assume that vehicle B is making a right turn while vehicle A proceeds straight and traverses the crossroads. Also suppose that the traffic light is green for A and red for C, which is also traversing the crossroads towards some other segment. Note that the movement of B is allowed and usually not controlled by traffic light, since it does not involve any crossroads crossing. Neither vehicle A nor B can see each other due to the stopped vehicle C. This can results in lateral collision. If the vehicles' sensor are able to communicate with each other, then vehicles at the intersection could avoid such a crash.

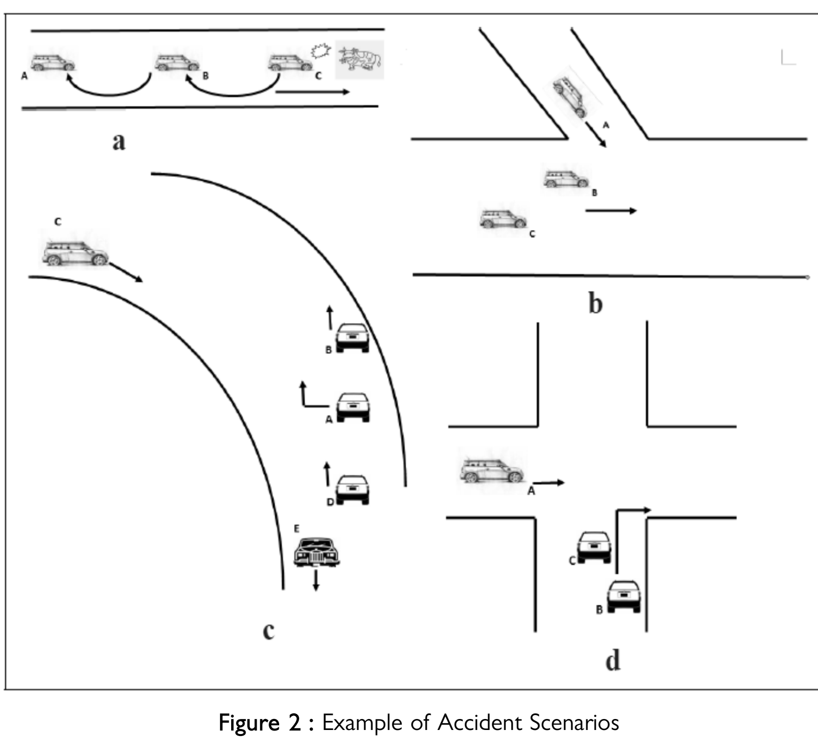

Figure 2 : Example of Accident Scenarios

Recently, some trends consisting in using WVSN for safety applications have been published.

A. Karpinski et al.

In [20], the authors focused on two-way single carriageway roads and suggested to put magnetic sensors in cat's eyes along the sides of the road in every few meters. They proposed a general solution allowing sensors to exchange information about the passing cars. This is to maintain realtime road-state information, which consists of the relative positions and speeds of all the vehicles traveling along the road.

In this solution, the software architecture of every node is composed of two layers: a lower layer containing

common functionalities, and a higher layer defining the various services that can be provided, like pedestrian on- road presence notification, erratic driving detection, road surface condition reporting, etc. Note that this project is in its early stage, and detailed descriptions of the general proposed software components are not published yet. Although the authors' aims is to inform the driver about events related to their safety, the solution can be extended to other kind of applications such as vehicle tracking and counting. This WVSN consists of nodes outside vehicles that collaboratively inform the onboard computers, i.e., there is no use of sensors in vehicles. Requiring sensors to be fixed in every few meters along roads will not allow to implement a scalable solution.

B. Sawant et al.

In contrast to the previous solution, Sawant et al. [26] rely on deploying of sensors in vehicle. They propose a general solution to form a multi-hop ad hoc network. To detect the presence of and the distance from in front obstacles and other vehicles the authors proposed to use onboard millimeter-wave radars, and possibly visual sensors or cameras. These devices can be useful to provide the driver with various information whenever available; However, they are relatively expensive compared to magnetic sensors, and not all vehicles can be equipped with them. In addition, the millimeter-wave radars are non-isotropic, i.e., their sensing angle does not cover all the 3600 around, unlike magnetic sensors. An inter-vehicle communication protocol that determines how exchanging the data sensed by the on-board sensors is utilized. In this protocol the messages are divided into two types: periodic and alert messages. Alert messages are generated by a vehicle in an emergency situation (e.g. after an air-bag deployment), while periodic messages are generated and transmitted at regular intervals by each vehicle. These messages are to inform the other vehicles about the vehicle's current parameters, such as the position, velocity, turn indication, etc. Periodic messages are addressed to direct neighbors, whereas alert messages may require multi-hop forwarding. Therefore, the communication protocol for the former consists in a simple broadcasting, but a routing protocol is required for the latter. For this purpose the authors proposed a

simple protocol, in which the sender selects an alert message count representing the number of hops through which the message has to be relayed, then each receiver decreases the count and forwards the packet to all neighbors until reaching 0.
Since not inevitably all the n-hop distant nodes in all directions may be concerned with the message content, a more sophisticated protocol is needed to select the appropriate receiver(s), and/or to decide whether to continue forwarding the message or not. For instance, after detecting a sudden vehicle stop within a lane in a freeway only the coming vehicles should be informed, and not vehicles moving in the opposite direction. It is useless and a waste of bandwidth to forward the alert in the opposite direction road. This may require the use of, the position information (using GPS), the node IDs, etc. To give priority to alert messages and support the use of different packet sizes the authors suggested to use IEEE 802.11e, which enables these features. The authors also suggested to dynamically form clusters in neighborhoods, such that the periodic messages are exchanged only between cluster members. This way, a potential receiver does not treat the message unless it belongs to the same cluster of the transmitter. However, no details were provided on how the clusters are constructed and maintained. Maintaining clusters is indeed problematic in such a highly mobile environment.

C. Xing et al. (LCS)

In [27] Xing et al. proposed a safety warning system using roadway sensors. They suggested to uniformly deploy roadway sensors along the road (for each direction of the highway), in every one unit distance. Thus, the topology of a highway sensor network is simply a line graph for each direction. The sensors detect and store safety-related event records, and submit these events each time a vehicle passes through. In-vehicle sensors' activity is limited to receiving these alerts. Each record corresponds to one occurrence of some event, and includes five fields: event ID, location, priority, index, and TTL. The event ID specifies the type of the event (e.g. fog, car accident, etc.). The location and the priority fields respectively consist of the geographic position of the occurrence of the event, and its priority. More importantly, the index value determines which sensors will store the event and for how long distance (units) the event will be propagated, while the TTL value tells how long the event will be safeguarded. The proposal focused on the storage, and lies on the "Location-centric storage (LCS)" protocol. This protocol implements an interesting design philosophy: the closer the driver to the event location, the more number of warning messages he may get. The mechanism used to ensure this is as follows: each detector of the event (sensor) stores the event and informs every passing vehicle about it, and also relays it towards the sensors located opposite the road direction (towards coming vehicles). Each sensor continues the propagation until reaching the number of hops specified by the index field. However, not each forwarder stores the event, but it does so iff it is in the one of the following positions $x + 21 - 1$, $x + 22 - 1$, ..., $x + 2\sigma - 1$, where x is the position of the detector sensor, and σ is the index value. After that, every node storing the event (for the specified TTL) informs the passing vehicles. This way, the density of the nodes storing the event decreases with the distance from the event location. The distance between two subsequent nodes storing the event exponentially increases with the distance, and the driver gets more alarms

(the time separating two alarms decreases) as long as he approaches the event location. The authors mathematically analyzed their protocol's features, and made some simulations.

Still, this solution lacks precisions on how the packets are to be broadcast to vehicles and relayed between roadway sensors, i.e., it completely ignores the communication aspects. Further, it does not provide any precisions of which kind of sensors to be used. Further, the authors suggested that the distance unit, i.e. the distance separating two subsequent sensors, to be a bit less than the sensor communication power range. This arises the following questions: First it is highly questionable if the sensing range is close to the order of the communication range, as the latter is in the range of 100m or even more while the former is usually much shorter. Second, it is impractical to put a sensor at each unit distance all along highways, (even though we assume it is in the order of the sensor communication range). It would be more rational to integrate in-vehicle sensors for participation in event detections.

D. Yoo et al.

This is another solution dealing with two-way single carriageway roads [28], which represents a potential danger to accidents. The authors proposed a solution to make the overtaking in this kind of roads safer. The proposal focuses on the communication issues, and relies on the use of onboard sensor motes. Suppose there are two vehicles traveling in the same direction one behind the other, each one equipped with a sensor mote running the proposed protocol. First, the solution assumes that each onboard mote detects the other by receiving its ID that is broadcasted periodically. When the trailing vehicle's driver wants to overtake the leading one, its mote first sends a request to the other. After the reception of the request a LED (light-emitting diode) glows to inform the driver that the back vehicle driver wishes to overtake him. Afterwards, and according to his visibility and estimation of the safety of this overtaking (e.g. whether there is an approaching vehicle invisible to the other driver, or a band etc.) the driver launches a response that is coded and transmitted back by its mote to the other mote. Finally a LED glows indicating the response for the other driver.

The solution is simple but interesting for employing onboard sensors, and being a specific-application centric. However, many shortcomings should be tackled. The assumption each mote can detect the other by simply using an ID broadcasting protocol cannot be fulfilled when there are other motes in their communication range. In this case, how the sender can know which ID amongst the received ones corresponds to the front vehicle's mote. This information is mandatory, as in the protocol the request is directly addressed to that mote. In addition, relying on the driver response (human perception) is not practical as it causes high latency, it is usually inaccurate, and the driver may be unwilling or unable to manually respond to such requests when driving. A simple example of inaccuracy is when the driver may not see an approaching vehicle because of weather conditions (e.g. fogs) or weak lighting. Using roadside sensors may help in this case to capture this vehicle. By interconnecting these roadside sensors with onboard ones, and possibly enhancing the latter with sensing capability instead of being limited to sending/receiving messages, it would be possible to effectively automate the response to the overtaking request.

E. Djenouri et al.

In [29] a WSN-based solution has been proposed, allowing vehicles with merely onboard sensors to avoid frontal collisions when overtaking. The solution assumes each vehicle to be equipped with a magnetic sensor, and an accelerometer sensor including a GPS receiver. Sensor transceivers are supposed to integrate directed antennas. The authors also suppose each route segment to have a unique ID, and that at the intersections (the segments delimitation points) a simple beacon with directed antenna broadcasts the ID of segments in the appropriate direction and angle. Using all these assumptions, the authors proposed a distributed protocol to be executed between onboard sensors. When a driver tries to make an overtaking, the onboard sensor broadcasts an overtaking request packet that includes its current position and route segment. All onboard sensors receiving such a request use the captured information and a mathematical model to reply and provide their information. The mathematical model filters out overwhelming responses from nodes that do not affect the overtaking, to reduce the overhead and save resources. It also allows the node after a short period to decide about the overtaking safety. The protocol permits to alert the driver about dangerous overtaking. Notably, about the potential frontal collision with another approaching vehicle that is out of his line of sight, due to a band, weak lighting, fogs, etc. The assumptions are realistic, and the solution does not need any heavy infrastructure. The beacons are simple devices that simply broadcast a short message. A sensor

mote is enough for this task. Moreover, they are supposed to be placed merely at intersections, which is feasible. The solution would be more effective and useful in rural highways, motivated by high vehicle speeds (potential danger to overtaking) and lack of infrastructure (need of infrastructureless solution). However, it is too specific, and considers only overtaking safety in two-way single carriageway roads. In practise, a safety system would integrate more services, and such a solution may be just a part of a bigger and more complex system.

F. Discussion

Some WVSN based applications ensuring vehicular safety have been recently proposed, as reported and discussed in this section. Still, many challenges must be overcome before the implementation in the real world. In case of employing onboard sensors (in-vehicle) the energy shortage of WSN fortunately does not exist, but the high mobility problem arises. For communication, ad hoc routing protocols may be used or adapted with possibly some modifications [18], but a comprehensive study on the efficiency in high mobility conditions is first needed. Since communication are usually multi-cast, new coordination mechanisms to select the appropriate recipients for each message are needed. For instance, at an intersection an approaching vehicle should be provided only with useful information related to vehicles that may affect its movement through the intersection (their positions, speed, direction, etc), whereas information of others such as of the ones that have just leaved the intersection should be kept away. In a freeway, an event like a sudden stop happening somewhere in one side of the road, should neither be reported to vehicles in the other side nor to vehicles that already passed the event location, but only to the approaching ones. Cooperative mechanisms that should be effective in high mobility conditions are then required to ensure this selective propagation. Moreover, at intersections in urban areas the wireless radio signals may experience important interference due to buildings surrounding the intersection. This issue may affect the communication between vehicles and must be addressed. On the other hand, when using roadside sensors all the limitations of WSN appear.

For communication between sensors the solutions proposed in the context of general WSN can be used. However, an efficient communication protocol between the sensors and vehicles needs to address the high mobility (of vehi- cles), which was generally neglected in WSN. Cooperation and coordination mechanisms to assist the propagation of the sensed information towards the appropriate nodes are also needed. At the vehicles side, mechanisms to distinguish the useful data that may interest the driver from the useless information are required. The use of both in-vehicle and roadside sensors is a promising architecture that allows to take advantages of both approaches. It will increase the availability of information, but will also create a really heterogeneous environment with respect to power supply, computation and storage capability, and mobility, i.e., some nodes are rich in power, as well as in computation and storage capability, but are highly mobile, and the others are fixed but with limited resources. In this situation, all the previous challenges should be addressed: i.e., the communication between fixed sensors, in-vehicle sensors, and finally and most importantly the communication between fixed and in-vehicle sensors. In all cases, the safety applications are realtime, and to be effective they require very low latency and very high reliability (packet delivery ratio). Therefore, the issue quality of service (QoS) is essential, and should be tackled by the solutions at all levels. Relaying on the driver response to requests should be eliminated and replaced by automatic responses from onboard sensors.

5. Traffic management and vehicle tracking

All solutions belonging to this class involve vehicle detection, vehicle classification, and speed estimation. Dealing with these issues is out of the scop of this work, which focuses on the networking aspects. Note that many approaches have been proposed and can be used, such like [30] that uses magnetic sensors and is appropriate for WVSN. In this section, two WVSN-based solutions belonging to this class are presented. Solutions relying on heavy vehicular infrastructure are not the subject of this survey.

A. Yoo et al

In [28], the authors proposed a solution for traffic management and traffic violation detection at at intersections. Their main goal was to reduce the waiting time at intersections by implementing a dynamic traffic signalling, in which the duration of the green light signal for any direction depends on the assessed number of vehicles in the

queue. In the implementation four motes were placed near an intersection of two roads, one in each direction (road segment .) The motes were equipped with light sensors, which counts the number of vehicles. When the vehicle passes above a sensor the light reading will inevitability fall below a defined threshold, resulting in the counter increase (a vehicle counting). Basing on the reported counter values, the next green light duration for each direction is computed, with a maximum time boundary.

The authors assumed to use two road signals: EW (east-west), and NS (north-south). The duration of each one depends on the maximum value of the appropriate counters. However, when changing the road is allowed at intersections (crossroads scenario) the movement of vehicles in the two segments of a road should not be allowed simultaneously. For example, when enabling the EW signal vehicles coming from the east segment turning to the south will affect the vehicles moving from the west to the east, and the same problem appears for the other signal. For each segment, a traffic light should be used and managed separately in this case. Moreover, in scenarios where the queue size exceeds the communication range of the sensor, the latter should be placed too far from the appropriate traffic light. In this case, the sensor cannot directly reach the traffic light. Using relaying sensors and multi-hop routing are required in this scenario. For traffic violation, the authors suggested to put four additional motes just after the stop line in each direction. These motes were programmed to beep whenever an automobile passes over this mote when the traffic signal is red for that particular direction.

B. Sharp et al (PEG)

Sharp et al. [31] proposed PEG, a WSN system that assists a pursuer robot to capture another evader robot whenever the latter enters an area where the Mica2 motes are deployed. The robots are mobile and simulate vehicles. The pursuer is known as the higher tier, and the sensors as the lower tier. The lower tier detects the evader and routes this information to the higher tier, which acts on this data to intercept the evader. This can be viewed as an actuation. Wherever the evader moves, the sensing and detection components of sensors of sensors capturing the evador will trigger detection events, and invoke the leader election algorithm for data aggregation. The elected leader will estimate the evader's position, and route the aggregated data as detections to the higher tier. When detections reach the higher tier, it traces a movement though a feasible route towards the evader.

This solution deals with all the communication and cooperation issues, ranging from the routing protocol, for which the authors proposed a tree-based protocol, to local detection, using magnetic sensors like in [30], and finally to leader election for data aggregation and position estimation. Realtime communication between the sensors and the peruser robot was also dealt with. In addition, the authors reported some encountered problems and provided practical advice for deploying realistic outdoor sensor network applications, including package design, debugging techniques, and high-level network management services. However, in the experience the robot's maximum speed was limited to 0.5m/s, which is clearly far from vehicular speeds. The robots' movement was in an open area, contrary to vehicular movements that occur in limited routes. Although the proposed approaches are promising and can be reusable by a variety of applications, especially applications involving vehicle tracking, more investigations (by real tests or at least by simulations) into more real situations of WVSN are mandatory.

C. Discussion

Both solutions presented above need vehicle monitoring and detections, but the second needs more information such as vehicle identification. Employing in-vehicle sensors may help to improve the sensing capability of the network, but is not as mandatory as in the safety applications. An onboard computer or any component that can receive information provided from the outside WSN is sufficient, i.e., no need of sensing with onboard sensors neither communications between these sensors. Relying on outside sensors is rational, as they can be placed only in limited areas and not all along the roads. Also, the latency is not a key feature for these applications. Reasonable delay may be required, especially for vehicle tracking, but is not as strict as in the safety applications. On the other hand, the data traffic load can be high, and thus aggregation techniques are essential. Further, security features such as authentication and integrity are of high importance.

In the future, putting adequate and interconnecting sensors at intersections and regions of high traffic concentration will provide drivers with useful information about the current traffic situation. Italso helps to efficiently manage traffic signals, and reroute drivers, which reduces traffic jam. Putting cameras or sensors enabling vehicle identification in strategic regions and interconnect them in a WSN can increase the security and assist police agents to pursue a criminals. Still, many challenges need to be overcome before these dreams come true. For traffic load management, appropriate selective broadcasting and propagation protocols are needed, along with a suitable WSN routing protocol. Data aggregation also must be considered since the traffic may be important. For the vehicle tracking applications, security is an additional requirement to prevent a malicious from misleading the pursuer by announcing false information or modifying packets initiated by legitimate sensors.

6. Environment and urban monitoring

A. Lee et al. (Mobeyes)

In [32] the authors dealt with proactive urban monitoring. They proposed the termed MobEyes system, which is based on the primary idea of exploiting vehicle mobility to opportunistically diffuse summaries about sensed data. They focused on the application where vehicles that are equipped with cameras and/or chemical detectors and located in the nearby of criminals who flee, sense and report the collected data to police authorities (collectors). Vehicle- local processing is exploited to extract features of interest. The WVSN regular nodes generate data summaries with features and context information (timestamp, positioning coordinates, etc.), then the collectors e.g., police patrolling agents, move and opportunistically harvest summaries from neighbor vehicles. They use summaries to identify, and then pump out only the data of interest from the vehicles. MobEyes has been constructed following the component- based architecture, allowing standard access to and diffusion of different kinds of sensed data. This simplifies the integration with heterogeneous sensors of different types and therefore enabling high portability and openness. The communication is constructed around two protocols: summary diffusion and summary harvesting. The first one is for disseminating the sensed information in the WVSN, in which every regular node periodically advertises a packet with newly generated summaries to its current neighbors that store them accordingly in their local summary database. Depending on the selected type of diffusion the node decides wether it relay this advertisement or not.

MobEyes supports both single-hop diffusion in which the receiver of an advertisement packet does not relay it, and k-hop diffusion where the packet is relayed up to k hops. Both kinds of diffusion are passive as only the source advertises its packets, contrary to the active diffusion where the node may advertises all packets included in its local database (generated and received). This maybe costly in terms of overhead. The advertisement to neighbors provides more opportunities to the agents to harvest the information, as both generated (sensed) and received data are reported upon request from the collector. The latter runs the harvest protocol, and requests the collection of diffused summaries by proactively querying its neighbor regular nodes in order to collect all the summaries generated in a given area. As it is only interested in harvesting summaries it has not collected so far, i.e. excluding the one already gotten, it includes a filter within the request enabling the regular nodes to put only the missing packets in the response. The responses are then acknowledged to ensure reliability. MobEyes also integrates some security mechanisms based on PKI encryption as well as temporal correlations with mutual observations. The aim is to eliminate forged and unauthenticated packets, and to ensure confidentiality and privacy. The authors evaluated their system by simulation. The reported results demonstrate the scalability of MobEyes up to thousands of nodes with limited overhead and reasonable latency. The results show that proper configurations of k-hop diffusion and police agents number help to achieve suitable tradeoffs between harvesting latency/completeness and overhead. Finally, note that MobEyes can be applied to a wide spectrum of applications, such as environment monitoring, by simply changing the type of the data to collect.

B. Cordova-Lopez et al.

In [21] the authors integrated the Geographical Information System (GIS) with a WVSN. They create an abstracted system able to detect, measure and transmit information regarding the presence and the quantities of a pollutant gas and their geographical location in realtime. The aim is to creating pollution maps in urban environments. In the framework, both onboard sensors and outside sensors can be used, along with GPS's information. Many onboard sensors may be used and interconnected through a Controller Area Network (CAN). They can be connected through a wireless connection to an outside sensor that can be embedded on top of traffic light. In their experience, the authors embedded pollution detection sensors in a mobile vehicle to control emission exhaust and the ambient

Pollution during a journey. They analyzed the density of different pollutant gases vs. the vehicle speed. The proposed framework is feasible when using on-board emissions diagnostic visual indicator [33] to warn the driver. This will allow to detect pollution in the exhaust of a vehicle, to inform the driver of existing pollutant levels and to activate appropriate alarms. This could trigger preemptive actions and create pollution maps on an urban scale containing details such as the types of cars, year of fabrication and fuel used. However, this solution is vague and lacks precisions on the protocols to be used, contrary to the previous one.

C. Discussion

As illustrated in this section, WVSN can be employed to monitor the environment and provide useful information, to assess the environment pollution and help to take the appropriate decision [21]. It can also help to increase citizen safety when monitoring the urban areas with respect to the existence of dangerous chemicals [32]. Contrary to the previous applications the ones reported in this section use onboard sensors, and take advantage of the mobility to sense multiple location with one sensor. Energy and low latency do not represent constraints to these onboard sensors based applications. Nonetheless, data traffic may be high, and the challenges related to mobility introduced before need to be addressed. Again, combining both onboard and roadside sensors could be beneficial to increase the availability of information.

7. Conclusion

The usefulness of WVSN was demonstrated in this paper. The possible enabled applications were addressed, ranging from vehicular safety, to traffic management and vehicle tracking, and finally to environment monitoring. The paper also provides an overview on the state-of-the-art and the research trends in this arena. Many challenges arise and should be coped with before passing to real implementations of WVSN. These challenges can be summarized as follows:

- The use of both in-vehicle and roadside sensors is a promising architecture. It enables the advantages of the two approaches, which will increase the availability of information. Nonetheless, this may create a really heterogeneous environment with respect to both power supply and mobility, i.e., a sub set of nodes are rich in power but highly mobile, and the others may be fixed but with low power autonomy. Therefore, WVSN's protocols and applications should take into account these differences and thus be heterogeneous, i.e., components to be executed by in-vehicle sensors have not the same constraints and thus should not be the same as the ones to be executed by roadside sensors.

- As multiple applications may co-exist in WVSN, the MAC protocol can play an important role to reduce the loss of critical packets. This can be achieved by assigning priorities to packets, such that more critical ones (of realtime safety applications for instance) are associated with higher priority. This way, the critical packets can be transmitted rapidly, requiring acknowledgments (ACK packets), and using higher power, which will help increasing the reliability and reducing their delay. To achieve this the MAC protocol should be application-aware, which can be achieved through a cross-layer design.

- Since multi-cast is usual in WVSN, new coordination mechanisms to select the appropriate recipients for each message are needed. This issue is application dependent and is used by the routing protocol, which also enhances the need for cross-layering.

- The feasibility of one hop communication (at the MAC layer) between roadside sensors and in-vehicle ones needs more study. The tests of [19] investigated the feasibility of communication between sensors in the same car. These sensors are relatively not mobile one to the other, even though the car itself was moving. For communication between a roadside sensor and an in-car sensor the relative mobility would be very high indeed, and equals the car's speed (since the roadside sensor is stationary), which may affect the delivery ratio.

- WSN routing protocols can be used for communication between stationary sensors (roadside), while mobile ad hoc routing protocols can be useful for communication between mobile ones (embedded in vehicles). However, the communication between the two kinds needs to be tackled.

- At intersections in urban areas the wireless radio signals may experience important interference due to buildings and urban infrastructure. This issue may affect communication between the vehicles, and thus need to be addressed.
- At the vehicles side, mechanisms to distinguish the useful data that may interest the driver from the useless one are required.
- For realtime applications, like safety applications, the protocols should assure low delay.
- Before passing to real implementations and test-beds, comprehensive simulation studies are required. All the real world constraints should be considered, e.g. high number of vehicles, high mobility, movement in delimited routes with all the route and urban constraints, instead of open space movement etc. Considering all these criteria is almost impossible in test-beds. This arises the need of a network simulator that integrates a realistic mobility model, and more importantly that allows the heterogeneous configurations (in-vehicle vs roadside sensors)

Référence bibliographiques

[1] I. Chisalita and N. Shahmehri, "Vehicular communication: A candidate technology for traffic safety," in IEEE International Conference on Systems, Man and Cybernetics, October 2004, pp. 3903–3908.

[2] J. Luo and J.-P. Hubaux, "A survey of inter-vehicle communication," School of computer and Communication Sciences, EPEL, Tech. Rep. IC/2004/24, 2004.

[3] C. Evans-Pughe, "The connected car," IEE Review, vol. 51, no. 1, pp. 42–46, 2005.

[4] G. Bilchev, D. Marston, N. Hristov, E. Peytchev, and N. Wall, "Traffimatics-intelligent co-operative vehicle highway sytems," BT Technology Journal, vol. 22, no. 3, pp. 73–83, 2004.

[5] M. Caliskan, D. Graupner, and M. Mauve, "Decentralized discovery of free parking places," in Proceedings of the 3rd International ACM Workshop on Vehicular ad hoc networks, VANET'06. ACM Press, 2006, pp. 30–39.

[6] D. B. J. Amit Kumar Saha, "Modeling mobility for vehicular ad-hoc networks," in the 1st ACM international workshop on Vehicular ad hoc networks. ACM Press, 2004, pp. 91–92.

[7] D. R. Choffnes and F. E. Bustamante, "An integrated mobility and traffic model for vehicular wireless networks," in The 2nd ACM international workshop on Vehicular ad hoc networks, VANET'05. ACM Press, 2005, pp. 69–78.

[8] A. Mahajan, N. Potnis, K. Gopalan, and A.-I. A. Wang, "Urban mobility models for vanets," in Proceedings of the 2nd IEEE International Workshop on Next Generation Wireless Networks, December 2006.

[9] F. K. Karnadi, Z. H. Mo, and K. chan Lan, "Rapid generation of realistic mobility models for vanet," in IEEE Wireless Communications and Networking Conference, 2007.

[10] C. Gorgorin, V. Gradinescu, R. Diaconescu, V. Cristea, and L. Ifode, "An integrated vehicular and network simulator for vehicular ad-hoc networks," in the 20th European Simulation and Modelling Conference, May 2006.

[11] B. David and A. David, "Dynamic source routing in ad hoc wireless networks," in Mobile Computing. Kluwer Academic, 1996, vol. 35, pp. 153–181.

[12] D. Djenouri, W. Soualhi, , and E. Nekka, "Mobility Models in Vehicular Ad hoc Networks: The Overtaking Impact," The Mediterranean. Journal of Computers and Networks (SoftMotor Ltd.), vol. 4, no. 2, pp. 62–70, 2008.

[13] M. M. Trivedi, T. Gandhi, and J. Mccall, "Looking-in and looking-out of a vehicle: Computer-vision-based enhanced vehicle safety,". IEEE Transactions on Intelligent Transportation Systems, vol. 8, pp. 108–120, 2007.

[14] B. Chang, C. Young, H. Tsai, R. Fang, and J. J. Lin, "Simulation and Implementation of High-Performance Collision Warning System for Motor Vehicle Safety Using Embedded ANFIS Prediction," in IEEE International Conference on innovative Computing Information and Control, Dalian, China, June 2008.

[15] Y. Chen, C. Zhang, and X. Huang, "A Novel Vehicle Safety Traffic Pre-warning Decision on Multi-sensor Information Fusion," in IEEE International Conference on Convergence Information Technology, Gyeongju, Korea, 2007, pp. 318–322.

[16] S. Biswas, R. Tatchikou, and F. Dion, "Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety," IEEE Communications Magazine, pp. 74–82, January 2006.

[17] M. Nekovee, "Sensor networks on the road: the promises and challenges of vehicular adhoc networks and vehicular grid," in Workshop on Ubiquit. Computing and e-Research, 2005.

[18] Yih-FuhWang1 and L.-L. Liu2, "Grey target tracking and self-healing on vehicular sensor networks," EURASIP Journal on Wireless Communications and Networking, vol. 2007, pp. 1–14, 2007.

[19] E. Peterson, "An investigation into intravehicle sensor networks," Department of Computer Science, University of California, Santa Barbara, Tech. Rep., 2007.

[20] M. Karpinski, A. Senart, and V. Cahill, "Sensor networks for smart roads," in PERCOMW'06: Proceedings of the 4th annual IEEE international conference on Pervasive Computing and Communications Workshops, Washington, DC, USA, 2006.

[21] L. E. Cordova-Lopez, A. Mason, J. D. Cullen, A. Shaw, and A. I. Al-Shammaa, "Online vehicle and atmospheric pollution monitoring using gis and wireless sensor networks," Journal of Physics: Conference Series, vol. 76, 2007.

[22] K. Akkaya and M. F. Younis, "A survey on routing protocols for wireless sensor networks," Ad Hoc Networks, vol. 3, no. 3, pp. 325–349, 2005

[23] S. Lee and W. S. an M. Gerla, "On-demand multicast routing protocol in multihop wireless mobile networks," Mobile Networks and Applications, vol. 7, no. 6, pp. 441–453, 2002.

[24] E. M. Royer and C. E. Perkins, "Multicast ad hoc on demand distance vector (maodv) routing," IETF Internet draft, Tech. Rep., 2000.

[25] K. Zeng, K. Ren, W. Lou, and P. J. Moran, "Energy aware efficient geographic routing in lossy wireless sensor networks with environmental energy supply," Wireless Networks, vol. 15, no. 1, pp. 39–51, 2009.

[26] H. Sawant, J. Tan, and Q. Yang, "A sensor networked approach for intelligent transportation systems," in The IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'04), October 2004, pp. 1796–1801

[27] K. Xing, X. Cheng, F. Liu, and S. Rotenstreich, "Location-centric storage for safety warning based on roadway sensor networks," Journal Parallel Distributed Computing, vol. 67, no. 3, pp. 336–345, 2007.

[28] S.-M. Yoo, “Sensor networks for automobile tracking and routing,” University Transportation Center for Alabama, Tech. Rep. UTCA Report 03303, March 2004.

[29] D. Djenouri, “Preventing Vehicle Crashes Through A Wireless Vehicular Sensor Network,” in IEEE Biennial Symposium on Communications, Ontario, Canada, 2008, pp. 320–323.

[30] S.-Y. Cheung, S. C. Ergen, and P. Varaiya, “Traffic surveillance with wireless magnetic sensors,” in 12th ITS World Congress, San Francisco, USA, November 2005.

[31] C. Sharp, S. Schaffert, and A. Woo, “Design and implementation of a sensor network system for vehicle tracking and autonomous interception,” in The 2nd European Workshop on Wireless Sensor Networks (EWSN 05), Istanbul, Turkey, January 2005, p. 93107.

[32] U. Lee, B. Zhou, M. Gerla, E. Magistretti, P. Bellavista, and A. Corradi, “Mobeyes: smart mobs for urban monitoring with a vehicular sensor network,” IEEE Wireless Communications, vol. 13, no. 5, pp. 1563–1284, 2006.

[33] R. Birnbaum and J. Truglia, Getting to Know OBD II. A S T Training, 2000.