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A Study of Wireless Sensor Networks for Urban Traffic Monitoring: Applications and Architectures

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Abstract

With the constant increasing of vehicular traffic around the world, especially in urban areas, existing traffic management solutions become inefficient. This can be clearly seen in our life through persistent traffic jam and rising number of accidents. Wireless sensor networks (WSN) based intelligent transportation systems (ITS) have emerged as a cost effective technology that bear a pivotal potential to overcome these difficulties. This technology enables a new broad range of smart city applications around urban sensing including traffic safety, traffic congestion control, road state monitoring, vehicular warning services, and parking management.
This manuscript gives a comprehensive review on WSN based ITS solutions. The main contribution of this paper is to classify current WSNs based ITS projects from the application perspective, with discussions on the fulfillment of the application requirements.

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Keywords: WSN, ITS, traffic management, traffic monitoring, traffic safety, parking management.

1. Introduction

Nowadays, traffic jam and high number of accidents in urban and metropolitan areas become more and more stressful and lead to dramatic consequences on economy, human health, and environment.

Existing ITS solutions detect vehicles in predefined positions. They are based on bulky and power-hungry devices, which use wired technologies for communication and power supply. This increases their installation, maintenance, and reparation cost and subverts the scalability of ITS affecting thus their major objectives [1]. Advances in embedded systems and wireless technology give birth to wireless sensor networks (WSNs), which are composed of cheap and tiny devices that communicate wirelessly and sense

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the surrounding environment. Each device node contains sensors, a processor, a memory, a radio, and energy source as depicted in Figure. 1. This technology has a great potential to overcome existing difficulties of ITS. With WSN, different types of motes can be used to sense, process and transmit data to optimally manage complex situations and enabling real-time adaptive traffic control systems. Data of interest includes position, traffic condition, local weather, images, acceleration, etc. Some possible sensors for ITS include magneto resistive, light, pressure, infrared, video, etc.

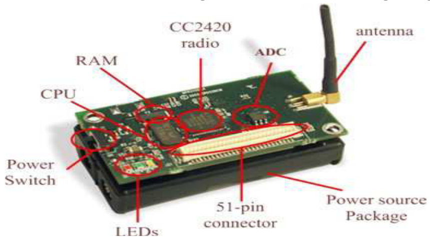

Figure 1 Mote components.

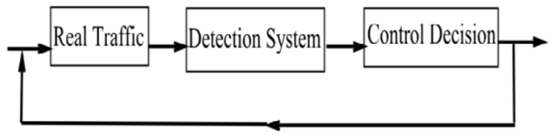

Figure 2 ITS mechanism.

The literature presents few surveys on WSNs based ITS. In [2], authors survey vehicular sensor network (VSN) platforms, while those of [3] discuss many urban applications. In this paper, WSN based ITS projects and solutions based on both on-road and/or in-vehicle sensors are reviewed. We **d**iscuss their architectures, analyze them according to several important performance criteria, and highlight some open issues. This work extends our previous study on traffic lights WSNs based projects [4].

The remainder of this paper will be organized as follows. Section 2 presents some applications of ITS with their requirements. In Section 3, some projects for traffic management that rely on WSN are presented. In Section 4, a discussion on the relation between traffic management applications and WSN architectures is investigated. Finally, Section 7 draws the conclusions.

2. ITS Applications: Requirements and Challenges

The ITSs attempt to manage optimally the urban traffic by enhancing safety, reducing travel time and fuel consumption at the aim of improving our daily life. It works as a control loop system where it senses traffic and road conditions using surveillance or detection system. The gathered information is communicated to the decision system to be organized and analyzed in order to take appropriate decisions. Figure 2 illustrates a simplified scheme of ITS.

WSN based ITS can be deployed in many application scenarios and may fit into many categories or diverge slowly from existing ones. So, applications' categorization has to be flexible because answering the needs of the operators and end users is the first goal of tracing classification.

As the purpose of ITS is traffic monitoring and management to improve life quality, ITS applications classification can include:

- **Drivers' safety:** Its principle is to transmit information related to accidents and weather in order to reduce the number and severity of crashes that lowers the number of deaths and injuries. It can be also used to guide ambulances and fire trucks.
- **Traffic Management:** the goal of such system is to minimize congestion of the whole traffic network and optimize the use of road capacity. This is done through traffic optimization and real-time traffic light control.
- **Smart cities:** It is clear that ITS's goal is enabling smart cities. So, this category covers the remaining applications. Because of limited space, we restrict our study to: (i) Traveler **Navigation Guidelines** to minimize cost, time, and fuel consumption, (ii) **Pollution Prevention** which become a sensible field and needs more and more attention, and (iii) **Efficient Parking Management** which may be also a field of traffic optimization but it falls also in smart cities sub-classes. Figure 3 summarizes our proposed WSN based ITS applications.

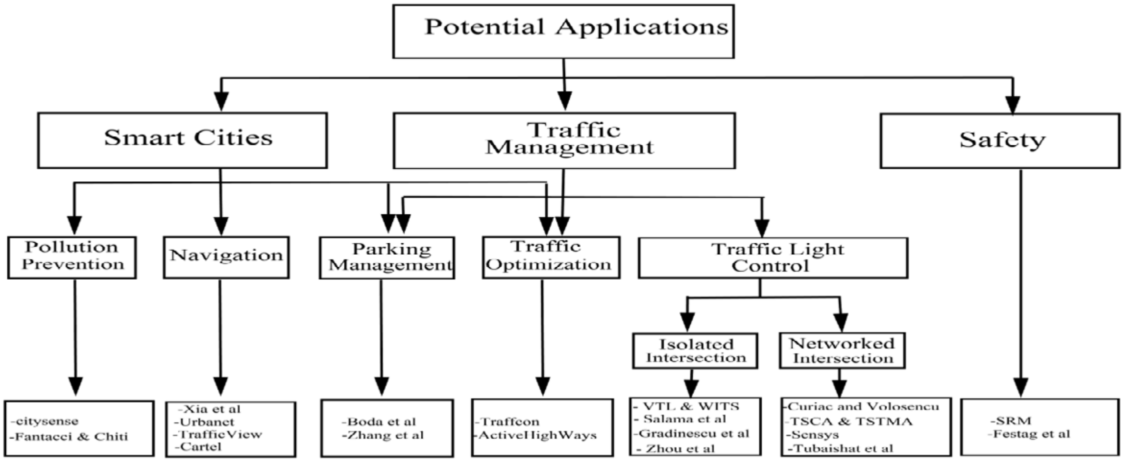

Figure 3 ITS Classification WSN Based projects

Despite their benefits over conventional systems, WSNs face many design challenges to fulfil ITS application requirements. This stems from their inherent properties such as: wireless communication, absence of physical protection and resource limitations. These challenges should be overcome by any WSN based ITS solution. Following a thorough analysis of ITS applications in our previous study [4], five main application requirements can be distinguished thus far namely: reliability, security, interoperability, end-to-end communication latency, and multimodal sensing.

- **Reliability:** In WSN based ITS many critical decisions must be token regarding the received information. So, the lost in some data packets can lead to undesired system behaviour. The harsh environment conditions and the lossy nature of wireless link raise the probability of lost which require reliable communication protocol.
- **Real-Time**: Despite receiving reliable information, real time reception may be also more or less critical regarding the application. Ensuring delay guarantee in WSN is challenging and must be dealt by the underlying solution.
- **Heterogeneity:** The coexistence of many WSN based ITS solutions technologies is primordial for long life of the system.
- **Security:** Wireless communications impose more security issues namely, jamming and criminality attacks, physical compromising of motes, etc. This makes security handling mandatory for any proposed WSN based solution.
- **Multimodal sensing:** An ITS application is subject to various type of environment measurement depending on the application and user's preference. Such measurements variables include: gas emissions, travelling delay, travelling tolls, etc. Consequently, the use of multimodal sensors by a WSN solution is more appropriate to efficient traffic management.

Table 1 presents a summary on the degree of importance the above requirements should be ensured by WSN for each type of ITS applications.

3. Projects on WSN-based Urban Traffic Management

Many urban sensing applications are developed thus far, including traffic monitoring, urban surveillance, and road surface monitoring. Some relevant projects are highlighted in the following, using their application field.

3.1. Traffic Management

3.1.1. Traffic Light Control

Controlling isolated or interconnected intersections from ITS point of view is to optimize its capacity utilization through managing the intersection parameters [13]. Many optimization algorithms were proposed in order to achieve this goal. Through the domain literature, off-line methods using historical measurements conduct to fixed time strategies while on-line ones using real time measurements give birth to traffic responsive strategies. This category can be ameliorated using WSN based ITS. Our previous study [4] focused on this ITS application type. In [14-16,18,20], the authors use on-road sensors to implement traffic light WSN based solutions. In [19,29,30] authors use on-road and on-vehicle sensors, while in [10] authors use only on-vehicle sensors.

Applications	**Requirements**				
	reliability	security	interoperability	Real time communication	Multimodal sensing
Traffic light	++	++	+	+++	+
Parking management	+	+	+	+	+
Traffic optimization	+	++	+	++	++
safety	+	++	+	++	+
Smart cities	+	++	+	++	++

Table 1 Applications' requirements

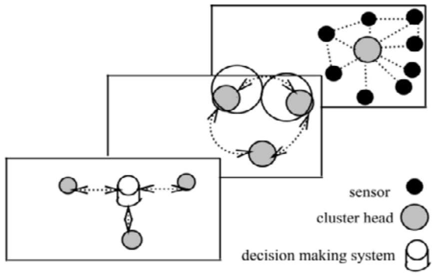

Figure 4 Three tier architecture.

3.1.2. Parking applications

In these applications, sensors are located on the ground and form a network to monitor vehicles entrance/exit to a parking lot, to update availability of parking spaces, and possibly to help orienting drivers towards these places.

Zhang et al. [17] propose a three level architecture system (Figure 4) where the lower one composed of sensors forming a cluster, monitoring the surrounding environment and fusing data through their cluster head. The middle level is the transmission and management composed of the cluster heads which communicate between them and transmit information to data terminal, the benefits to use two frequencies avoiding interference intra-cluster and inter-cluster heads is clear. The higher level is the decision-making level where the control is done to manage traffic and implement ITS strategies. The system is applied to parking management with a sensor per vehicle place to find available spaces and their location and inform drivers about it through interface. Sensors in each parking area form a cluster, sense empty places and notify the base station so that places will be displayed to users. The architecture used is efficient in many ITS applications but only parking application use don't need this architecture because the decision taken are not so complex and does not need so levelled system.

Boda et al. [21] design and implement a wireless sensor network using magnetic sensors for real-time available parking spaces and integrates it with telecommunication network (as telephony network), so that end users check for places using their cellular telephones. This work gains in cost by putting sensors in determined key locations rather than every vehicle place using a studied location scheme in the goal to know the number and location of empty places. There are three types of nodes which are the key location sensor nodes, the router nodes without sensors, and finally the base station which is simply the collecting node relayed to the computer.

Authors don't involve how to consume the available information or how to request for it. The relation between the number of sensors in the path and the surface is not explained apart the existence of a sensor at each turning lane and the half of the lane which are not sufficiently precise for long lane diameter. A Possible integration of the system with other ITS applications will enhance overall city driving.

3.1.3. Traffic optimization

From [43], the efficiency and optimization of traffic can be viewed from two perspectives. The whole ITS system goal is ensuring road fluency and minimizing accidents while individual driver goal is fast arriving with minimum cost. The authors propose a minimizing travel time algorithm that uses road sensor nodes measurement to estimate lane travelling time and choosing the fast one.

Collins and Muntean [23, 24] present TraffCon, which try optimizing the overall system efficiency rather than individual only demands by optimizing the whole network road capacity utilization through drivers re routing, changing lanes, etc. This goal is reached using a client server architecture where the clients interact with the server part using WAVE (Wireless Access in Vehicular Environments). The vehicles equipped with GPS gather road state information and the server make decisions using optimization algorithms (like genetic algorithms) to be consumed by clients through displays or audio media. So, the clients don't take decisions by their own and the system guideline respect drivers' comfort. Authors suppose that all vehicles are equipped which may not always be true.

The goal of Iftode et al. [22] in their Active high way paradigm is ensuring drivers' travelling time boundaries near of that ensured by train and airlines. This is done through scheduling in a flexible manner users' travels. To do, drivers reserve their travel through internet or in real time while driving. This permits them to drive in reserved lanes which cohabit with ordinary lanes. For ensuring system well work, real-time measurements of road state (congestion, accidents, weather related state, etc) is collected and sent to the decision maker server by different sensing mechanisms as vehicles' sensors, on road sensors. It is clear that the reservations and system orientations (speed, route changing, etc) need users' displays to be present, localization mechanisms are also required. The system takes into account security and privacy requirements to satisfy users' intentions and ensure system well functioning.

The idea behind Active highways is interesting but need more investigation to guaranty time bounds especially when internet reservation is done, the exact entrance moment may be relayed which perturbs the scheduling. The exit system from the high lanes needs more details because if the vehicle can't exit quickly it slows other vehicles in the lane.

3.2. Safety

The purpose of Jankuloska et al. [28] in SRM is to gather traffic information, which enhances system and driver safety, display them to drivers and authority (through SMS or e-mail), in order to take appropriate decisions. The traffic information in SRM concern violations of traffic signals by drivers (over speed driving, no respect of stop or direction interdiction signals, etc) or dangerous situations as accident' happening. VSN (vehicular sensor networks) is used in addition to on-road nodes combining so ad-hoc and infrastructure based scheme. The vehicle nodes, after sensing their environment, send data to the road node units which at their turn send the aggregated data to the data centre where decisions are taken. The Road units (RSN) communicate this decision to vehicle nodes. The Data Centre contains system data bases and is responsible of decision taken and transmission to authorities (like SMS to police cars). The inter vehicles communication are permitted and enhance system functionality by exchanging hazardous information. A real test of the prototype has shown its feasibility and benefit.

Authors propose this architecture for safety but it can be used also to enhance road capacity through sending the recommended speed avoiding congestion or to reroute vehicles through other empty roads. The use of RSN unit may be enhanced by introducing sensors in it. The communication between RSN units is not also highlighted which can increase the performance. Communication's security does not also be introduced.

The work in [5], presents a scheme to avoid vehicles collision using on-road and on-vehicle wireless nodes. This scheme is based on wireless signal quality and strength, where stationary on-road nodes send to approaching vehicles information about the in-intersection vehicles after detection using magnetic sensors. The authors test their system on a real prototype. But this work does not present how to secure communication or ensure their reliability as loss of information, when drivers trust on it, results on catastrophes.

Festag et al. [11, 12] work combines road sensor nodes to extend the vision of vehicle sensors, ensuring so driver safety. The WSN composed by road nodes send the aggregated data concerning road state such as weather and obstacles especially in harsh situation like forests and icy zones. The vehicles exchange these transmitted values to draw a more complete view. This architecture avoiding accidents is also used to ensure post accidents procedure (as drivers' responsibility). Data and transmission security is ensured using soft mechanisms in this scheme due its high importance especially for post accidents as data may stay for long time before being requested. Road sensors and vehicles communicate using IEEE 802.15.4 and vehicles use IEEE 802.11p to distribute the information in multi-hop manner. The solution was tested through a real implementation. The proposed scheme may be used for traffic management. As it combines road side sensors, the overall system performance may be enhanced. The use of access points may also enhance the application. Authors introduce the security of storage which is important and introduce security when requesting the databases. But storing the data in the WSN itself is not so interesting compared to the use of gateways especially for long time storage and the exploitation of stored data will be easier from requesting the WSN.

3.3. Smart cities

The work presented by Fantacci and Chiti [25] servers, among others, to sense environment pollution level load. It is composed by road sensors, in vehicle sensors, and interconnected access points. The access points gather information from the both nodes' type, aggregate and encode them, and send them to the mobile vehicles which are not restricted to a dedicated access point. The consumption of this information by the vehicles is through a displayer and serves to take appropriate decisions concerning congestion avoidance, pollution load balancing in the whole system, optimum route choice, etc.

Authors focalize on efficient gathering and coding operations ensuring also reliability. But they don't introduce inter-vehicles communication which can enhance system performance. Also the integration of this system with other ITS application to manage traffic is not introduced. The information presented to drivers may be augmented with orientations to guide drivers to take right decisions. The use of pollution information must be system based to avoid drivers' ignoring.

The system proposed by Xia et al. [26], whose goal is helping intelligent navigation and path planning, is composed of vehicles equipped with different sensors communicating between them and having on board displays, road sensors that send road state like vehicles speed to sink sensor nodes where data is stored, and data centre where decision are taken after receiving sinks data. The data centre sends utile information to end users in their vehicles and to traffic deciders to take appropriate reactions. As an example of the system functioning is traffic jam detecting and route changing. The vehicle noting its speed staying low for a long time transmits a message to the sink through sources on-road sensors. This last, after a significant messages number receiving, broadcasts to vehicles and data server the road jamming state. The vehicles broadcast this message to enlarge the coverage. A system prototype was also tested by authors. The scheme used in this work is interesting. But authors don't give enough details on algorithms used to perform path selection. The integration of this system results' are not explored for traffic management, like adaptive traffic lights. Security communication is not introduced; even authors highlight its necessity and application reliability for well application running.

Hull et al. develop "Car Tel" [27], which is a mobile sensing and computing system that uses phones and on-board vehicle devices. Each node gathers, processes, and delivers sensing data to a central portal, where the data is stored in a database for further analysis and visualization and constructing a reusable software platform for many mobile traffic sensing applications. CarTel nodes rely on wireless technologies (Wi-Fi, Bluetooth, other CarTel nodes and mobile phone) to communicate with the portal.Car-Tel project includes traffic mitigation [31,32], road surface monitoring and hazard detection [33], vehicular networking [34], privacy protocols, intermittently connected databases.

The model used by Cartel is very interesting especially the heterogeneity handling of different communication technologies. But including static on-road sensors and actor infrastructure to the same system network may enhance system performance, especially when many existing cars don't dispose on-board sensors or displays. Cartel permits drivers to know about jams and statistical data but don't give enough details on traffic management or guiding which may be added easily to it as cartel is conceived in a modular manner.

As smart phones offer complex computation, huge storage, and long-range communication, Urbanet[7] proposed by Riva and Borceause them as multi sensor (audio, video, etc) devices creating a wireless mobile ad-hoc sensor network and act collaboratively to provide sensing coverage, collect and share data enabling users to exploit sensor-rich world. Urbanet is a middleware platform that enables applications running on mobile devices (smart phones and vehicular systems) to collect real-time sensed data in a decentralized manner without dedicated servers or Internet. It optimizes resource utilization to the sensing activity, network conditions, and local resources. Urbanet proposes a mobile application for drivers to detect traffic jams in a city. It presents three middleware platforms for three different programming models. The model proposed in Urbanet is interesting but does not use collected data from different kinds of sensors to manage traffic. Attaching Urbanet with existing infrastructure will also enhance the overall system performance and will permit using additional ITS applications. Urbanet interest on programming applications but does not give details on communication protocols and security mechanisms which needs also investigation.

Nadeem et al. [8,9] present TrafficView which provides drivers with traffic conditions information to be used in route planning and driving during special weather conditions causing low visibility. Each vehicle is supposed having a computing device with a display, a short-range wireless interface, and a GPS receiver. Vehicles gather and broadcast information about them and other vehicles they know about, in an ad-hoc manner (car-to-car communications).Localization algorithms using angles between roads and vehicles speed are developed in this project, too. Traffic View model has been used in Traffic management protocol [29], but the integration of this model with on road sensors will enhance the performance. Also the integration of this model with the infrastructure will also help especially for requesting through internet based browsers. A security communication is envisaged by authors in following versions.

CitySense [6] is an urban sensor network testbed developed at Harvard University and BBN Technologies. It consists of 100 wireless sensors deployed across a city (on light poles, private or public buildings) in Cambridge, MA. Each node is an embedded PC, with dual 802.11a/b/g radio interface, and various sensors for monitoring weather conditions and air pollutants. Users reprogram and monitor CitySense nodes via Internet. The testbed contains wire line gateways linking the wireless mesh to the Internet, and back-end servers for reprogramming and monitoring, storing data generated by user jobs, and a web-based interface to end users. Citysense can be used as a backbone to test applications using on road sensors for traffic monitoring and management.

4. Discussions and Open Directions

WSN based ITS applications can be categorized according to sensors placement as well as to the network architecture. Following the literature, it has been shown in our previous study [4] that WSN based ITS can be classified regarding the sensors placement into in-vehicles, on-road, or both. From the architectural point of view, we can classify WSN based ITS applications according to the use or not of infrastructure into ad-hoc based architecture, infrastructure based architecture, or hybrid ad-hoc and infrastructure based one. Combining these previous classes give birth to different WSN based ITS network applications.

In this section, we will discuss the impact of using these classes of architectures and sensors placement on the performance of the proposed application type-based taxonomy. The preferred architecture to application mapping, following our study, are summarized in Table 2. It is obvious that the recommended network choice based on the above mentioned classification differs depending the applications need, the cost involved, and the wireless technology used. In fact, on-road sensors gather data in cities to be used in different applications such as adaptive traffic lighting, and to take the appropriate decisions even in the absence of vehicles sensors [14-16,18,20]. They permit collecting useful data when implanted in hard driving roads, harsh weather conditions areas like tornado and icy zones in the purpose to avoid accidents.

While in the other hand, in-vehicles sensors are for important benefit in infrastructure monitoring as bridges state, and road potholes. Furthermore, they instrument a larger geographical area with a less number of sensors compared to on-road sensor networks (like in CAR-TEL [33]). They also avoid traffic jam, and enhance drivers' security through traffic information exchange. However, in some traffic management applications such as traffic light monitoring, supposing all vehicles dispose on-board sensors or display devices, like proposed in [10], is not yet the case. Therefore, the taken decisions may be wrong and engender dramatic results on human life and materials.

Ad-hoc based architecture is adopted by many WSN based ITS solutions [10,11,12]. The ad-hoc feature enables multi-hop communication extending thus the coverage. However, this architecture is exposed to failures due to batteries' drain, bad links, and security attacks.

architectures	**Applications**				
	Pollution prevention	Parking lots	Traffic optimization	Traffic light	safety
Ad-hoc On- road	+	+		+	
Ad-hoc On-vehicles	+		+		+
Ad-hoc hybrid	+	+	+	+	+
On-road with BS	+	+		+ +	
On-vehicles with BS	+		+		+ +
Hybrid with BS	+ +	+ +	+	+ +	+ +
Hybrid Ad-hoc and BS	+ +	+ +	+ +	+ +	+ +

Table2 architectures use in ITS applications

Infrastructure-enabled architecture overcomes the above mentioned drawbacks. In this scheme, the base station is power unconstrained with long transmission range that enables it to reach all sensors and coordinates them efficiently [15,22,23]. However, the expensive installation restricts its utilisation into urban areas, keeping so vehicles in isolated areas out of ITS help.

Contrary to shortcoming cited in the two previous architectures, in hybrid ad-hoc and infrastructure-enabled scheme, devices can communicate using available infrastructures (Wifi, Wimax, Cellular, BS) when it is located within the transmission range of access point, or using multi-hop ad-hoc communications in the absence of infrastructure [27-30]. This kind of architecture is the most efficient and takes advantage of all the available architectures. Table 3 summarizes the reviewed WSN based ITS solutions.

An efficient ITS must capture many environmental measurements in order improve the traffic quality of service. For example, a traffic light network of a whole city can use weather and climate (air pollution) values to choose sequences time length in addition to the collected real-time data concerning vehicles (speed, queue length, etc). Also, green route planning in dense cities, which is a sort of load balancing of gaze propagation, can be used in conjunction to congestion and distance parameters. From the discussion above, it is obvious that WSN based ITS bring a large added value but need more research efforts.

Whilst many WSN based ITS solutions which achieve acceptable performances have been proposed, numerous open directions related to improving traffic management and safety can be envisaged. Using smart phone sensors with their innovative applications is an emergent sensing combination.

Answering the requirements is more or less rigorous depending on the application type. But generally speaking, the fundament of any successful WSN based ITS applications must ensure security, end-to-end reliability, privacy, real time and mobility supporting. The commercialization of finished products, which is already starting, must focus on these aspects.

5. Conclusion

Intelligent transportation systems are necessary for nowadays traffic management, but the huge traffic makes traditional ITS methods out of scalability and real time responding. WSN helps to join the classical ITS system drawbacks, due to its cheapness and scalability nature. Even that, much research keeps essential to make WSN the suitable partner, as seen in the literature projects.

In this paper, we highlighted some existing works of this field, showing their application type, architectural aspect, and pointing out some weaknesses following the application requirements.

solutions	architectures							applications					Validation tests	
	ad-hoc On-road	Ad-hoc on vehicles	Ad-hoc hybrid	On-road with BS	On-vehicles with BS	Hybrid with BS	Hybrid Ad-hoc and BS	Pollution prevention	Parking lots	Traffic optimization	Traffic light control	safety	simulation	experimentation
CURIAC and VOLOSENCU [14]				+						+	+		-	-
Sensys [15]				+							+		+	+
Tubaishat et al [16]				+							+		+	-
Youcef et al [18]				+							+		+	-
Zhou et al [20]				+							+		+	+
Gradinscu et al [29]							+				+		+	-
Chen et al [30]							+			+			+	-
Salama et al [19]				+							+		-	-
Ferreira et al [10]		+									+		+	-
Zhang et al [17]				+					+				-	-
Boda et al [21]				+					+				-	+
Jankuloska et al [28]							+					+	-	+
Collins and Muntean [23]					+					+			+	-
Festag et al [11, 12]			+									+	+	+
Fantacci and Chiti [25]						+		+		+		+	+	-
Xia et al [26]						+				+		+	-	+
Iftode et al [22]					+					+		+	-	-
Hull et al [27]							+			+		+	-	+
Riva and Borcea [7]		+								+		+	-	-
Nadeem et al [8,9]		+								+		+	-	+

Table 3: A summary of projects architectures and applications.

References

[1] Mounib Khanafer, Mouhcine Guennoun, Hussein T. Mouftah. “WSN architectures for ITS systems”. NTMS09.

[2] Uichin Lee, Mario Gerla. “A survey of urban vehicular sensing platforms”. Computer Networks 54 (2010) 527–544.

[3] Abhijit Sharma, Rituparna Chaki, Uma Bhattacharya. “Applications of WSN in ITS: A Review”. ICECT11.

[4]Mohamed Amine Kafi, Yacine Challal, Djamel Djenouri, Abdelmadjid Bouabdallah, Lyes Khelladi, Nadjib Badache. “A study of Wireless Sensor Network Architectures and Projects for Traffic Light Monitoring”. ANT 2012.

[5]Yahia Tachwali, Hazem H.Refai. “System prototype for vehicle collision avoidance using wireless sensors embedded at intersections”. Journal of the Franklin Institute 2009.

[6] Rohan Narayana Murty, Geoffrey Mainland, Ian Rose, Atanu Roy Chowdhury, Abhimanyu Gosain, Josh Bers, and Matt Welsh. “CitySense: an urbanscale wireless sensor testbed”. International conference on technologies for homeland security, 2008.

[7] Oriana Riva, Cristian Borcea. “The Urbanet Revolution: Sensor Power to the People!”. PERVASIVE computing, 2007 IEEE.

[8] Sasan Dashtinezhad, Tamer Nadeem, Bogdan Dorohonceanu, Cristian Borcea, Porlin Kang, Liviu Iftode. “TrafficView: a driver assistant device for traffic monitoring based on car-to-car communication”. Vehicular Technology Conference, 2004. VTC 2004.

[9] T. Nadeem, S. Dashtinezhad, C. Liao, and L. Iftode. “TrafficView: A Scalable Traffic Monitoring System”. MDM 2004.

[10] Michel Ferreira, Ricardo Fernandes, Wantanee Viriyasitavat, Ozan K. Tonguz. “Self-Organized Traffic Control”. VANET’10.

[11]Andreas Festag, Alban Hessler, Roberto Baldessari, Long Le, Wenhui Zhang, Dirk Westhoff. “Vehicle to vehicle and road side sensor communication for enhanced safety”. The 9th International Conference on Intelligent Tutoring Systems - ITS'08.

[12] Jens-Matthias Bohli, Osman Ugus, and Dirk Westhoff. “A secure and resilient WSN roadside architecture for ITS”. WiSec’08.

[13] D. Jiang, V. Taliwal, A. Meier, W. Holfelder, R. Herrtwich. “Design of 5.9 GHz DSRC-based vehicular safety communication”. IEEE Wireless Communications 13 (5) (2006) 36–43.

[14] Daniel-Ioan CURIAC, Constantin VOLOSENCU. “Urban Traffic Control System Architecture Based on Wireless Sensor-Actuator Networks”. International Conference on Manufacturing Engineering, Quality and Production Systems. (MEQAPS'10).

[15] http://www.sensysnetworks.com/home

[16] Malik Tubaishat, Yi Shang and Hongchi Shi. “Adaptive Traffic Light Control with Wireless Sensor Networks”. CCNC 2007.
[17] Mingchen Zhang, Jingyan Song and Yi Zhang. “Three-Tiered Sensor Networks Architecture for Traffic Information Monitoring and Processing”. Intelligent Robots and Systems, 2005. (IROS 2005). 2005 IEEE/RSJ International Conference on.
[18] Khalil M. YOUSEF, Jamal N. AL-KARAKI1 and Ali M. SHATNAWI. “Intelligent Traffic Light Flow Control System Using Wireless Sensors Networks”. JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 26, 753-768 (2010).
[19] Ahmed S. Salama, Bahaa K. Saleh, Mohamad M. Eassa. “Intelligent Cross Road Traffic Management System”. ICCTD 2010.
[20] Binbin Zhou, Jiannong Cao, Xiaoqin Zeng and Hejun Wu. “Adaptive Traffic Light Control in Wireless Sensor Network-based Intelligent Transportation System”. Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd.
[21] Vamsee K. Boda, Asis Nasipuri, and Ivan Howitt. “Design Considerations for a Wireless Sensor Network for Locating Parking Spaces”. SoutheastCon, 2007. Proceedings. IEEE.
[22] Liviu Iftode, Stephen Smaldone Mario Gerla James Misener. “Active Highways (Position Paper)”. Invited Paper, PIMRC08.
[23] Kevin Collins, Gabriel-Miro Muntean. “TraffCon: an intelligent traffic control system for vehicular networks”. IET CIICT07.
[24] Kevin Collins and Gabriel-Miro Muntean. “A vehicle route management solution enabled by Wireless Vehicular Networks”. INFOCOM Workshops 2008, IEEE.
[25] Romano Fantacci and Francesco Chiti. “Urban Microclimate and Traffic Monitoring with Mobile Wireless Sensor Networks”. Book chapter: Wireless Sensor Networks: Application-Centric Design, Geoff V Merrett and Yen Kheng Tan (Ed.), InTech. (2010).
[26] Rongyan Xia, Chen Ye, Dongdong Zhang. “Vehicle to Vehicle and Roadside Sensor communication for Intelligent Navigation”. Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on.
[27] Bret Hull, Vladimir Bychkovsky, Kevin Chen, Michel Goraczko, Allen Miu, Eugene Shih, Yang Zhang, Hari Balakrishnan, and Samuel Madden. “CarTel: A Distributed Mobile Sensor Computing System”. in Proc. ACM SenSys, 2006.
[28] Bisera Jankuloska, Milan Zahariev, Aleksandra Mateska, Vladimir Atanasovski, and Liljana Gavrilovska. “SRM: Traffic Regulations Monitoring Using VSNs”. 17th Telecommunications forum TELFOR 2009 Serbia, Belgrade, November 24-26, 2009.
[29] Victor Gradinescu, Cristian Gorgorin, Raluca Diaconescu, Valentin Cristea, Liviu Iftode. “Adaptive Traffic Lights Using Car-to-Car Communication”. Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th.
[30] Wenjie Chen, Lifeng Chen, Zhanglong Chen, and Shiliang Tu. “WITS: A Wireless Sensor Network for Intelligent Transportation System”. The First International Multi-Symposiums on Computer and Computational Sciences IEEE (IMSCCS'06).
[31] Arvind Thiagarajan, Lenin Ravindranath, Katrina LaCurts, Sivan Toledo, Jakob Eriksson, Samuel Madden, Hari Balakrishnan. “VTrack: Accurate, Energy-Aware Road Traffic Delay Estimation Using Mobile Phones”. SenSys, Berkeley, CA, November 2009.
[32] Arvind Thiagarajan, Lenin S. Ravindranath, Hari Balakrishnan, Samuel Madden, Lewis Girod. “Ctrack: Accurate, Low-Energy Trajectory Mapping for Mobile Devices”. Proc. NSDI, Boston, MA, 2011.
[33] Jakob Eriksson, Lewis Girod, Bret Hull, Ryan Newton, Samuel Madden, Hari Balakrishnan. “The Pothole Patrol: Using a Mobile Sensor Network for Road Surface Monitoring”. MobiSys, Breckenridge, U.S.A., June 2008.
[34] Jakob Eriksson, Hari Balakrishnan, Samuel Madden. “Cabernet: Vehicular Content Delivery Using WiFi”. MOBICOM08.
[35] X.F. Chen, Z.K. Shi, “A dynamic optimization method for traffic signal timings based on genetic algorithm”. Journal of System Simulation, Vol 16 No.6. Chinese Association for System Simulation.Beijing, 2004, pp.1155- 1161.
[36] X.F. Chen, Z.K. Shi, “Real-coded genetic algorithm for signal timing optimization of a single intersection”, ICMLC02.
[37] S. Takahashi, H. Nakamura, H. Kazama, and T. Fujikura, “Genetic algorithm approach for adaptive offset optimization for the fluctuation of traffic flow”. The IEEE 5th International Conference on Intelligent Transportation Systems, 2002, pp.768-772.
[38] Q.R. Li, L.Y. Wei, and S.F. Ma, “The model analysis of vehicles situation and distribution in intersections based on Markov process”. Proceedings of 2003 IEEE International conference on Intelligent Transportation Systems. vol 2, 2003 , pp.1076-1080.
[39] Dennis I. Robertson and R. David Bretherton. “Optimizing Networks of Traffic Signals in Real Time-The SCOOT Method”. IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 40, NO. 1, FEBRUARY 1991.
[40] A. G. SIMS AND K. w. DOBINSONIEEE. “The Sydney Coordinated Adaptive Traffic (SCAT) System Philosophy and Benefits”. TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. VT-29, N0.2, MAY 1980.
[41] Ergen, S.C. Varaiya, P. “PEDAMACS: power efficient and delay aware medium access protocol for sensor networks”. Mobile Computing, IEEE Transactions on. July 2006.
[42] Binbin Zhou, Jiannong Cao, Hejun Wu. “Adaptive traffic light control of multiple intersections in WSN-Based ITS”. VTC11.
[43] CHEN Wenjie, GAO Liqiang, TU Shiliang. “An intelligent guiding system for transportation network based on WSN”. CIT05.