Chapter 3
Towards Heterogeneous Architectures of Hybrid Vehicular Sensor Networks for Smart Cities

Soumia Bellaouar, Mohamed Guerroumi, Abdelouahid Derhab and Samira Moussaoui

Abstract Smart cities are increasingly playing a fundamental role in managing the city's asset. Smart transportation is an important building block of a smart city as it can efficiently resolve many issues related to the traffic on the road. Vehicular ad hoc networks (VANETs) in smart cities may ensure wide inter-vehicle communication and disseminate data and safety-related information. VANETs have their specific characteristics such as long lifetime battery energy, high mobility, and large storage capabilities. In certain circumstances, VANETs may not ensure timely detection of road events and connectivity between vehicles due to their low density, high mobility, or low deployment of roadside unit (RSU) infrastructure. Wireless sensor networks (WSNs) are equipped with low processing and low storage capabilities but they ensure high detection of events. To overcome VANETs limitations, and as VANET and WSN have complementary characteristics, the combination of VANET and wireless sensor network (WSN) technologies into one hybrid architecture enables to identify new aspects and fields of intelligent transportation systems and may offer new services for the smart cities. In this kind of hybrid network, sensor nodes have small size and can be deployed densely inside the road to monitor traffic, roads status, and weather conditions. This chapter describes the hybrid vehicular sensor networks and discusses their deployed applications, communication paradigms, challenges, and existing architectural solutions. Moreover, a heterogeneous VANET-WSN architecture is proposed and open issues and future directions are discussed to help stimulating future studies in this emerging research field.

Keywords Hybrid vehicular sensor network · VANET · Wireless sensor network WSN · Cloud computing · IoT · Smart city

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3.1 Introduction

With the growth of population and economic development inside urban environments, the daily life problems of citizens become more complicated. Thus, the smart cities are increasingly becoming an effective approach to solve these problems, and hence the number of digital devices (sensors, actuators, and smart appliances) as well as connected vehicles on the road is growing day by day to manage the city for better decision-making.

One of the main goals of smart cities is to minimize their transportation problems, which caused congested roads and accidents. Vehicular ad hoc networks (VANETs) aim to solve these issues by improving the vehicle mobility and having more safe smart cities. Moreover, wireless sensor networks (WSNs) are considered as a fundamental infrastructure to provide services for smart cities. Their versatility and their diverse usage help to measure and collect a lot of data that may enhance the daily life of the smart city's citizens. Initially, the development of vehicular technologies focused on building efficient and safer roads [1]. But nowadays, due to the huge development of wireless technologies and their application in vehicles, it becomes possible to use hybrid wireless vehicular sensor network. This network aims to reduce pollution and congestion, prevent accidents, and ensure easier communication among vehicles and infrastructures and safer roads. For instance, sensors and embedded systems are used on an automated highway system. This system makes the experience of driving less burdensome with fewer accidents, especially on long trips by making the highway itself part of the driving experience and integrating roadside technologies that allow using the system more efficiently [2].

Motivation

The development of smart cities is based on deploying smart technologies such as: sensors, smart vehicles, and technological devices on roads, which might lead to several issues in the smart city like the deployment cost and the integation of different technologies. This can influence the main objectives of developing a smart city such as safety and quality of living. Hence, by taking the heterogeneous environment into account, a study of numerous deployments of WSNs in smart transportation for smart cities needs to be explored. Sensor services for gathering specific data are utilized in VANET-WSN, regarding the monitoring and supervising of each cyclist, vehicle, parking lot and air pollution control [3]. Vehicular wireless sensor network can provide monitoring systems and infrastructures with more efficiency, lower cost and better safety.

Consequently, the vehicular wireless sensor network contributes in managing cities and improving the different features of human life by creating cost-effective services with more efficiency, and reducing traffic congestion, accidents, and pollution. Thus, this network helps to ensure citizens' safety to improve the quality of their lives through different applications. Therefore, the main contributions of this chapter are as follows:

- We identify the architectures and systems of hybrid vehicular wireless sensor networks.
- We provide a classification of different vehicular wireless sensor network applications for smart city, as well as a taxonomy classification of these networks with respect to: architecture, information, and access technologies.
- We propose a multilayer and heterogeneous architecture for hybrid vehicular wireless sensor networks.
- We discuss the main open issues of wireless sensor vehicular networks and identify possible future directions.

Chapter Organization

In the rest of this chapter, we outline the requirements of smart cities in Sect. 3.2. In Sects. 3.3 and 3.4, we present the requirements of smart transportations in smart cities and we present the communication technologies used by the connected vehicles. In Sect. 3.5, we identify the objectives of VANET-WSN in smart city and discuss their applications and their implementation challenges. In Sects. 3.6 and 3.7, we describe architectures and systems of VANET-WSN and discuss the existing testbed platforms and simulation environments. In Sect. 3.8, we give a short description of our proposed multilayer VANET-WSN architecture. In Sect. 3.9, we present the remaining open issues and outline possible future research directions with an architecture that we propose. Section 3.10 concludes the chapter.

3.2 Requirements of Smart Cities

Nowadays, the way of living, communication and habits of citizens have changed. The digital technology is included in our environment, social and economic life to provide a high quality of life. A smart city requires some already clear items for urban environments such as smart health care, smart water distribution, smart transportation and there will surely be others in the future. The main components composing the smart urban environments are as follows [3, 4]:

- **Smart health care**: To monitor patients' health parameters and truck ambulance through sensor devices. These systems identify the status of the patients and the location of the ambulance in order to provide real-time information on the patient's health and faster decision-making.
- **Digital signage systems**: These help to provide advertising services where the customers can buy the ticket of concert posters via the billboard.
- **Smart grids systems**: To maximize the energy efficiency by providing the necessary amount of electricity depending on the demand.
- **Smart urban lighting systems**: These adjust the intensity of the light depending on the presence of people on the street with minimum energy wastage.

- **Smart city maintenance systems**: To notify the City Council of any damages in the urban elements through notifications sent from the citizen's smart phones, in order to repair the damage faster.
- **Transportation and vehicular traffic networks**: To provide a considerable source of data in smart cities. The citizens and the government can significantly use the traffic data by employing a proper analysis. The vehicular traffic information is used to identify mainly traffic congestion and accidents. This information allows analyzing the traffic and notifying the officers, but in order to generate large amount of information, it requires high-capacity communication infrastructure. The smart transportation can provide the following functionalities:
- **Smart parking systems**: These aim at finding parking spaces and guide drivers to the exact location. They allow reducing air pollution.
- **Intelligent public transport systems**: To control and manage public transportation networks, maintain their performance, and provide passengers and decision-makers with up-to-date information about trips and network operating conditions.
- **Traffic management systems**: To manage the traffic lights and inform drivers about the best route to take in order to reduce congestion.
- **Smart taxi applications**: That allow finding and booking the closest taxi without the human intervention.

3.3 Requirements of Smart Transportation Networks

Nowadays, vehicles have the capabilities to communicate and share useful information with each other or with the roadside unit (RSU) under a network known as VANETs [5]. This network has been developed to provide security, information service and comfort (video, Music, internet access, etc.) for drivers and passengers. The demand of existing and emerging smart transport applications is increased, while the number and requirements transport components are continuously growing. Therefore, the wireless vehicle sensor network deployed in a smart city must provide flexible, efficient, and easy to use services. It requires less effort/time consumption as well as a minimum of interaction [6]. The main requirements that should be considered in the deployed transport system for smart cities are as follows:

- **Fault-tolerant systems**: The smart devices and systems participating in the smart city environment must be available. In some situations, when an accident or a natural disaster occurs, the system must work to propagate important information about the situation and damage. Moreover, the transport systems must be able to decrease or eliminate peaks in resource request.
- **Energy Efficiency of communication**: The problem of energy consumption does not exist in VANETs. In a smart city, the transport system is heterogeneous. We can find collaboration between several systems and technologies in

order to perform a specific task. For this reason, the development of lightweight communication protocols can ensure more energy-efficiency related to new technologies and achieve sustainability and quality of communication. Also, the transport system must implement fast and reliable communication protocols to enable real-time interactions between the smart roads and the smart vehicles.
- **Security and safety mechanisms**: The architecture of smart transport must provide adequate security mechanisms to prevent a hacker from taking control of the vehicle and compromising the decision-making solutions. In addition, the security mechanism must consider the real-time contextual factors and ensure adaptive planning travel and monitoring systems based on current traffic situation.

3.4 Communication Technologies for Connected Vehicles

Wireless communication is important for vehicles as it allows sharing and exchanging necessary information between vehicles to make decisions, and which might influence the behavior of motorists or drivers.

The detection devices are implemented on the vehicles or on the roads. They offer several designs of connected vehicles in smart transportations. The VANET provides a wireless communication between moving vehicles based on a dedicated short range communication (DSRC) for low overhead operation 802.11p with a maximal bit rate of 27 Mb/s. It is achieved through a wireless medium WAVE family 1609 stack [7]. Vehicle can communicate with other vehicles by establishing vehicle-to-vehicle communication (V2V) or communicate with RSU next to the road by forming vehicle-to-infrastructure communication (V2I). These wireless communications have limited bandwidth. However, the data traffic, which is required by some devices such as HD camera and 3D imaging, is continuously growing [8].

In a smart city, there is a lot of wireless devices deployed for several purposes all over the city (on roads, buildings, etc.). For that, other types of communications can be used in smart transportation. Existing works attempt to integrate commercial WiFi, Bluetooth, ZigBee, WiMax, LTE (4G), and the five generation (5G) into vehicles. They allow longer range communication and high throughput that could not be supported by the primary communication DSRC. The vehicles can communicate with the sensors deployed on the road (at the edge of the road, in the middle of the road, according to an urban grid, etc.) using, in general, the Zigbee 802.15.4 technology to exchange different information [7]. This vehicle-to-sensor communication allows the interaction between vehicles and WSN which means that the vehicles must be equipped with different communication interfaces not only with 802.11p. In addition, vehicles can communicate with pedestrians using 3G or WIFI access technologies. This communication aims to find mechanisms to ensure pedestrian safety [9]. The smart cities allow vehicles to interact with the environment, i.e., roads, residential buildings, market places, and collaborate with different systems such as smart healthcare systems and cloud computing systems. These offer more computing capabilities and more specified services related to smart transportation. However, embedding the vehicles with these devices might increase the deployment cost, which requires making a compromise between the benefits offered by the communication technology and its corresponding deployment cost.

3.5 VANET-WSN

3.5.1 Definition

Hybrid VANET-WSN (V-WSN) network is a VANET, which is extended by deploying wireless sensor nodes along the road especially on highways. Sensors act as access points (APs), monitor, and control traffic flow in real time and detect incident on roads [10]. The main objective of this network is to improve transportation safety and relieve the difficulty of communication in this network.

In the context of smart city, sensors are deployed in city zones for large fields and applications, so hybrid V-WSN network can collaborate and communicate with other networks with different technologies (3G, LTE, etc.), as shown in Fig. 3.1.

3.5.2 Objectives

The vehicular wireless sensor network deployed in a smart city must provide flexible, efficient, and easy to use services. This leads to identify the following main objectives:

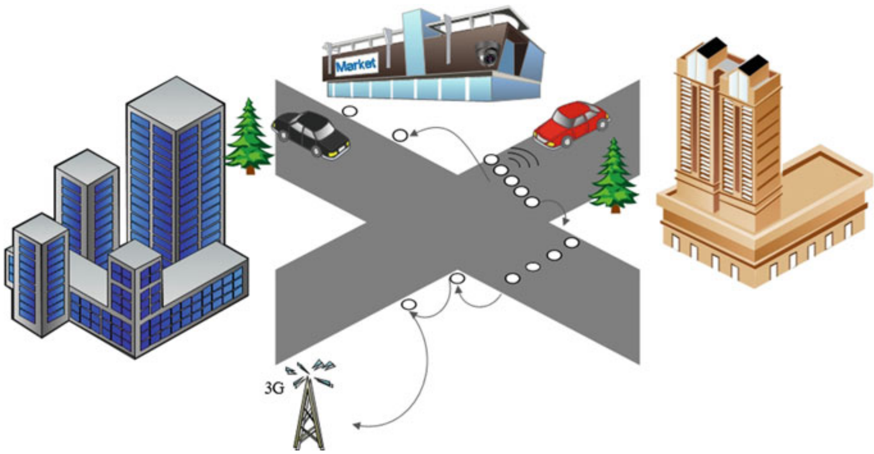

Fig. 3.1 Hybrid V-WSN network

- Deploy services to the users on the road through various applications [11].
- Set up and maintain a communication networking among vehicles without any central base station [12].
- Ensure an optimal and efficient way of communication to enable real-time interactions.
- Provide adequate security and reliability mechanisms to prevent incidents.
- Provide reliability and timeliness solutions by considering the delay requirement and real-time contextual factors.
- Ensure collaboration and cooperation between smart transportation systems and others smart systems such as social and economic networks.

3.5.3 Applications

Many transport infrastructures, bridges, and tunnels have collapsed due to natural disasters or because of poor maintenance. For example, in 2007, the bridge in Minneapolis killed 13 and injured 145 people. In 2008, this bridge was rebuilt using a sensing system to collect data regarding structural behavior and corrosion [13]. Smart road applications need more than vehicle devices. Smart and reliable unmanned aerial vehicles (UAVs) are recently used in smart roads to automate road infrastructure components. UAVs can be equipped by DSRC interfaces to enable wireless communication under VANETs [14]. For example, a set of UAVs replaces a road support team. It could fly around the location of an incident to provide basic support or report the situation of the traffic.

Several IT functions have been integrated into the vehicles to give a wide variety of applications and services. As shown in Fig. 3.2, applications and services in the V-WSN networks can be classified as follows:

Monitoring/Management Applications

These are based on the exchange of information related to the state of the road. Monitoring bridges are a successful application of smart roads. For example, the six-lane, 2.9 km Charilaos Trikoupis Bridge in Greece is outfitted with 100 sensors that monitor its condition. After opening it in 2004, the sensors detected vibrations in the cables holding the bridge, which led engineers to install additional weight to dampen the cables [13]. Moreover, monitoring airflow to visibility and gases (CO, CO_2, NO_2, O_2, SH_2, and PM-10) inside tunnels are some parameters to monitor air tunnels quality [13].

Security Applications

These are the most important applications in smart transportation because road accidents cause death, especially among young people. Road safety is significantly improved thanks to alert messages exchanged between fixed or mobile entities of the network. Safety applications can use UAVs such as flying accident report agent

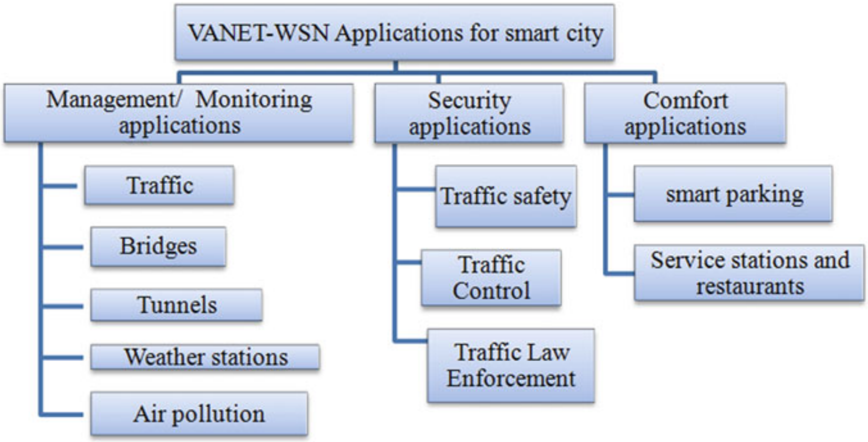

Fig. 3.2 Hybrid basic classification of V-WSN application

or flying police eye. When a traffic accident occurs, UAVs might help the rescue team to reach the accident scene within the shortest time [14].

Comfort Applications

These allow accessing the Internet, suggesting popular spots, hotels, and shopping malls for tourists or citizens. An intelligent navigation services application allows recommending the best route to drivers by considering some parameters such as: the least time-consuming route and the most energy-saving route [15]. Moreover, smart parking applications minimize the amount of time spent by the individual to look for parking [16].

3.5.4 Issues and Challenges

Smart V-WSN technologies in smart cities need to cope with population growth while ensuring long-term sustainability with optimized operation cost, and be resilient to disasters and failures. A design and operation challenge is to have a good mix of smart technologies. So, the vehicular wireless sensor networks are rather sufficiently smart to be sustainable for years. The challenges for building smart V-WSN are the following:

Heterogeneous Wireless Networks Designs

The optimal deployment of heterogeneous wireless sensors in the road requires careful consideration and design of appropriate protocols such as fast and reliable MAC access protocol and data forwarding mechanisms. This allows to guarantee timely transmission of critical messages and to deal with the high redundancy of the transmitted information.

Interoperability Among Heterogeneous Wireless Networks

The architecture, resource allocation, mobility management, quality of service (QoS) provisioning, and security of deployed systems need a uniform conception to enable communication among different wireless networks. It is required to pay considerable attention to address this challenge in the future.

Cost

The financial cost is related to the design, the network operations and the cost of deploying such a smart technology. The progress of science and technology would make the smart technology cheaper in the future and would not impose additional taxes on citizens [17].

High Energy Consumption

The energy consumption rate of resource-constrained devices in smart city is significantly high. In the future, and with the growing number of citizens, the energy consumption rate of communication technologies will still be considered as high. Future V-WSN devices must ensure control and optimization of renewable energy sources.

Security and Privacy

Users request high level of privacy and security guarantees in order to participate to such a system. These requirements represent major concerns that need to be addressed to encourage larger participation of users of mobile devices to the mobile sensing applications [18]. Security includes enhanced emergency- response services, and automated messages for alerting drivers and pedestrians and real-time information on available roads. While authenticating the vehicle, the privacy related to identity and location information must be kept private.

Efficiency

Higher efficiency of V-WSN systems can reduce the operational cost and improve sustainability of the smart transportation. Any smart city design needs to take these potential disasters and failures into consideration, so that the city can quickly recover from such situations [17].

3.6 Architecture of V-WSN

VANET provides a wide variety of communication architectures, especially with the emerging of some technologies such as IoT, cloud computing, smart grid, and UAV. The most known communication classifications are VANET communications in-vehicle domain, ad hoc domain, and infrastructure domain [19] or geocast/

broadcast, multicast, and unicast approaches [20], and one-hop or multi-hop communication [21]. We classify the V-WSN architecture based on the used concept as explained below.

V-WSN Architecture

A recent trend consists of using WSN in VANET applications to improve driving safety and traffic efficiency. The deployment of sensors on selected roads is serious issue. The authors in [10] considered the deployment of a minimal number of APs (i.e., RSUs and sensors) along the two sides and the median island of the road considering a two lanes which represent the road as a grid.

Depending on the application type and requirements, the proposed communication architecture differs from one another in V-WSN network. For traffic monitoring application, the proposed architecture [20], which was implemented in two cities of South Africa [22], consists of WSN sensors, RFID scanner, and TMC.

For effective and efficient vehicle-sensor and sensor–sensor interactions, we distinguish several propositions. The sensor nodes can have two types: the regular sensor node and the AP sensor node. Regular nodes are deployed between two adjacent APs to sense and relay messages, APs have extra responsibilities of discovering and communicating with vehicles, and managing the network, which is based on two types of clusters: Vehicle clusters and sensor clusters (Regular nodes between two APs form cluster). Usually in this hybrid network, the vehicle nodes have two communication interfaces: WIFI IEEE 802.11 interface and ZigBee IEEE 802.15.4 interface [23], but we can that find sensor nodes have a ZigBee IEEE 802.15.4 interface and the sink node has two interfaces: a IEEE 802.11p interface and a ZigBee IEEE 802.15.4 interface for communication WSN-sink-vehicle while vehicle nodes have IEEE 802.11p interface [24].

The cooperation between WSNs and VANETs permits to extend the transmission range of ad hoc nodes. Vehicles store road information in the WSN's sink when they pass through WSN. Other cars obtain the information stored (e.g., weather conditions, location of accidents, possible building, etc.) from the WSN's sink [25]. The same idea was used for pollution-free monitoring system using a hybrid V-WSN and LTE-M technology. This technology is deployed on moving buses, and Zigbee wireless sensors are deployed on the bus stations as fixed nodes. When buses stop on the stations, the modules of LTE-M can collect air data from Zigbee wireless sensors directly or the sensors transmit the data to the sink node of the cluster. Then, the sink node feeds a database or either using direct USB or Ethernet. The data collected are sent to the cloud where they are analyzed [26].

Reference Architecture of V-WSN

For an effective distribution of tasks, the subsystems have been devised into the following systems [27]: *Sensing subsystem*, *distribution subsystem, decision-making subsystem, and the execution subsystem.* These are presented in Fig. 3.3.

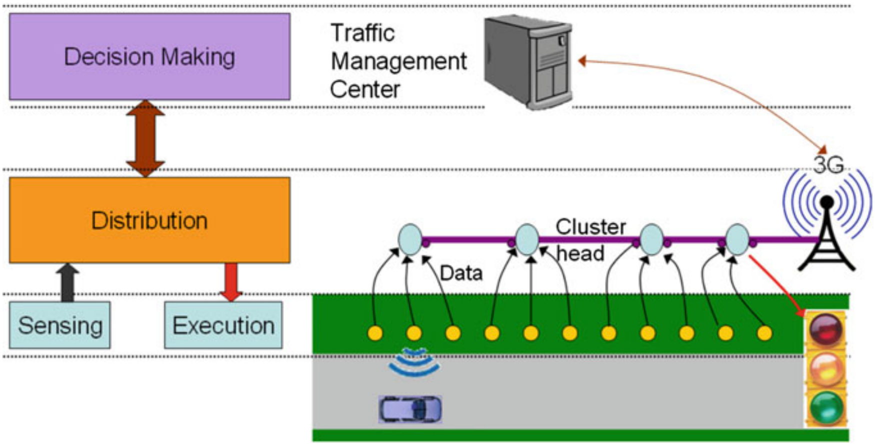

Fig. 3.3 Reference architecture for WSN-based ITS applications (adopted from [27])

- *The sensing subsystem* is composed of all the devices responsible of sensing information relative to road and traffic state.
- *The distribution subsystem* allows exchanging information between different parts of the system.
- *The decision-making subsystem* plans the necessary actions in order to achieve the objectives of the application. It can be a centralized traffic management control (TMC), which is a decision-making center, WSN nodes, or other devices.
- *The execution subsystem* performs actions that foster changes in the traffic flow.

Vehicular Cloud Computing

The new paradigm vehicular could computing (VCC) is based on mobile cloud computing. It has attracted researchers in order to provide more road safety and more traffic applications for smart city. VANET clouds are divided into three architectural frameworks named vehicular clouds (VCs), vehicles using clouds (VuC), and hybrid vehicular clouds (HVC) [28]. We distinguish permanent cloud and temporary cloud for VANETs [29]. The permanent VANET-Cloud presents the conventional cloud while the temporary VANET-Cloud sub-model consists of VANET computing resources and passenger devices. VANET-Cloud groups infrastructure components into three layers: Client layer, communication layer, and cloud layer. *Client layer* consists of general end users; *Communication layer* consists of several communication devices and networks: Internet gateways, wireless networks such as VANETs, WSN, 3G/4G networks, and *cloud layer* (a permanent and temporary cloud) refers to the VANET-Cloud services [29]. We can also notice that another V-CLOUD architecture is divided into three layers: in-car vehicular cyber-physical system, vehicle-to-vehicle network (V2V), and vehicle-to-infrastructure (V2I) network layers. The communication architecture is cluster based. The vehicles on highways form clusters based on defined road segmentation. Each cluster is organized as a node in cloud computing and there is one cluster head to send all information to other vehicles in each cluster as well as to neighboring cluster heads. There are two types of sensors: a vehicle's internal physical sensors and smart phone embedded sensors. They are used to monitor health and mood conditions of the driver.

The VCC is not only used for resource sharing and intensive computing, it can be used for storage, routing and other smart city vehicle applications. For instance, VC transport management (VICTiM) provides assistance for the traffic management services, mechanisms for the storage of the information and use of different communication protocols, which calculate the efficiency to propagate the messages or not. To successfully accomplish data broadcasting with less local resources, the vehicular networks should be connected to the cloud where the routing information using RST equipped with internet. The user can use their GPS, camera, sensors, WiFi network, mobile apps, storage services, and computers to access the VC data [30].

The cloud can also be used in smart parking application where the architecture system consists of three layers: A sensor layer, a communication layer, and an application layer. At the application layer, an information center provides cloud-based services. At the communication layer, various wireless technologies provide connection between the application and the sensor layer, based on the ABC&S communication paradigm [31]. Also dissemination protocol for VANET, such as cloud computing-based message dissemination protocol for VANET (ClouDiV), combines the use of cloud computing infrastructure and cloud structure based on OnBoard computers of vehicles. ClouDiV uses a proactive approach, which is applied by each data center in order to discover fresh and updated routes, and use a reactive approach, which is performed by each vehicle aiming to find the nearest data center [32].

VANET and IoT

A novel concept of a universal network framework including all the existing heterogeneous networks is being strongly experienced and shaped due to the highly growing number of things; IoT is revolutionizing many new research and development areas. Internet of Vehicle (IoV) is one of the revolutions brought by IoT. Communications in IoT can be considered as a hybrid communication because large number of things can communicate with different ways and technologies.

Each vehicular communication of IoV is enabled using a different wireless access technologies (WAT). The communication architecture includes vehicles, RSUs, and a range of communication devices, which makes the architecture more complex. The realization of heterogeneous vehicular network architecture is a challenging task.

The major network elements of IoV network model are the cloud, connections, and the clients. Several networks are integrated into the IoT architecture such as the social networking, which brings the Social Internet of Vehicles (SIoV) paradigm. In this social network, every node establishes social relationships with other objects in an autonomous way. Social relationships can be established among the vehicles in

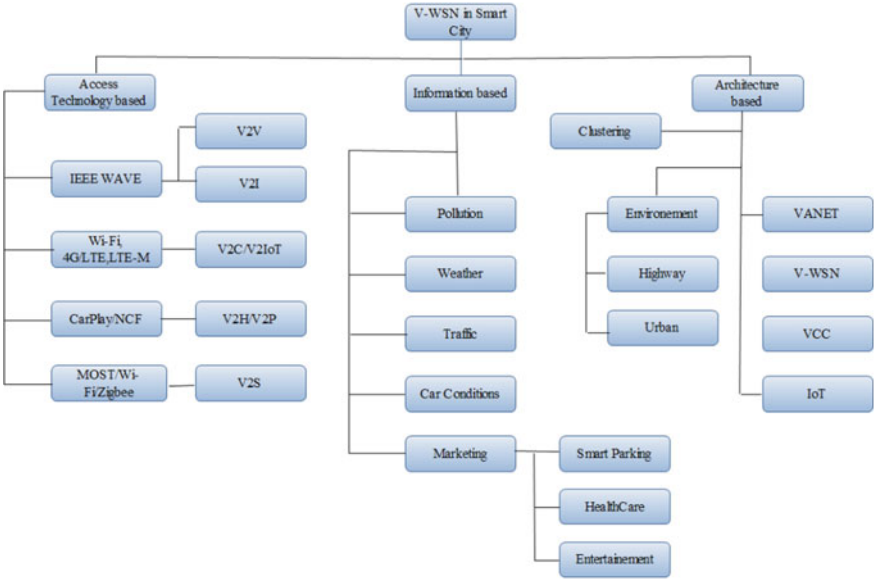

Fig. 3.4 Classification of V-WSN in smart city

order to provide useful and trustworthy information and services to the vehicles. These relationships can be either static between vehicles belongs to the same automaker or dynamic between vehicles comes through V2V communications [33].

The evolution of research and technologies allowed the construction of smart cities and the Internet of things which can deal with challenges of VANET communications and their architectures. We present a classification of VANETs architecture.

In Fig. 3.4, we propose a classification of V-WSN model in smart cities. There are different classification criteria considered in vehicular wireless sensor for smart city model. We distinguish three possible classes, architecture based, information based, and access technology based. Each service designed in V-WSN must support the hybrid network model.

3.7 Testbeds of V-WSN

A coherent smart vehicular wireless sensor framework is required to support heterogeneous domains of smart city and the specific requirements of information and communication technology (ICT).

Existing simulation systems can be used to evaluate the performance of the developed V-WSN protocols in smart city due to the inaccessibility or the high cost of the needed resources. Many researchers use simulators such as ns-2, ns-3, and

OmNet++ to validate their proposed ideas and approaches. They used a vehicular mobility model like SUMO, VanetMobiSim, and SIDRA TRIP. Some research projects have developed platforms integrating both network and traffic simulators to improve the solutions evaluation. Veins and iTETRIS are the most known open source platforms for V-WSN. Veins is based on OMNeT++ and SUMO, and iTETRIS, which integrates NS-3 with SUMO [18].

The smart vehicular sensor networks have recently risen in prominence due to significant advances in enabling device technologies. With this emergence of interconnected devices and services in smart cities, the V-WSN has become the major extension to the current mobile networking infrastructures.

However, the V-WSN exceeds the scope of currently available deployments mainly due to two issues. First, current deployments of V-WSN are essentially closed and tailored solutions to specific application domains. Second, new technologies and solution optimizations are constrained in terms of applicability to the context under which they have been tested.

Therefore, the V-WSN in a smart city requires an agreed architectural reference model, based on open protocol solutions and key enabling services that enable interoperability of deployed smart city resources across different application domains and contribute to their integration to a globally interconnected infrastructure. Some projects target experimental test facility for the research and experimentation of architectures to evaluate scientific research under real-world operational conditions as shown in Table 3.1. In [34], the researchers designed a mobile sensor computing system called CarTel. It is a mobile-embedded computer combined with a set of sensors. CarTel nodes collect, process, deliver, and visualize data from sensors located on mobile units. CarTel has been deployed on six cars, running on a small scale in Boston and Seattle for over a year. It has been used to analyze commute times, analyze metropolitan Wi-Fi deployments, and for automotive diagnostics.

Another testbed for vehicular mesh networking was presented in [35], called HarborNet. It is based on cloud data, and has been deployed in the seaport of Leixões in Portugal. It allows controlling network and collecting data from moving trucks, cranes, two boats, and roadside units. In [36], the researchers built a VC testbed called VCbots. The latter contains major hardware components: robot vehicle on board, mini cloud, remote cloud, and management server. It allows reconfigurable testing environment without any assistance of infrastructure. The common architecture of these testbeds is shown in Fig. 3.5. Table 3.1 presents a comparison between these testbeds.

3.8 Heterogeneous V-WSN Architecture System

To leverage the functionalities of V-WSN networks in smart cities, we propose a new hybrid vehicular architecture model called heterogeneous VANET-WSN architecture. The latter integrates several technologies and concepts such as cloud

Table 3.1 Comparison of some sensor vehicular testbeds

Testbed	Nodes	Communication	Data	Operations	Cases studies
CarTel	Mobile (equipped with GPS)	Wireless (WiFi, Bluetooth) or mobile phone flash memories, or USB keys	Heterogeneous	Traffic monitoring, environmental monitoring, civil infrastructure monitoring, automotive diagnostics, geo-imaging, data muling	Commute time road traffic, traffic hot spot heuristics, wide-area Wifi measurement
HarborNet	Trunks, cranes, tow boats, patrol vessels (all equipped with GPS), and roadside units, connected to the optical fiber backbone of the sea port, and cloud-based data	Wireless (IEEE 802.11p/wave, Wi-Fi interface (IEEE 802.11a/b/g/n) 3G interface)	Heterogeneous	Control of experiments via IEEE 802.11p links and/or the cellular backhaul, delay-tolerant operation, performance measurement (received signal strength indicator (RSSI), packet delivery ratio (PDR) and the bandwidth)	The network coverage offered by the vehicular mesh network and three roadside units, the dynamics of the connections established by trucks via the vehicular mesh network
VCbots	Robot vehicle (VC-truck, VC-van, 1VC-sedan, VCcompact)	Wireless (WiFi, LTE, IEEE 802.11p/wave)	Heterogeneous	Group-based message dissemination for road hazard avoidance, platooning, cross coordination	Vehicle cooperation application (implement a platooning algorithm)

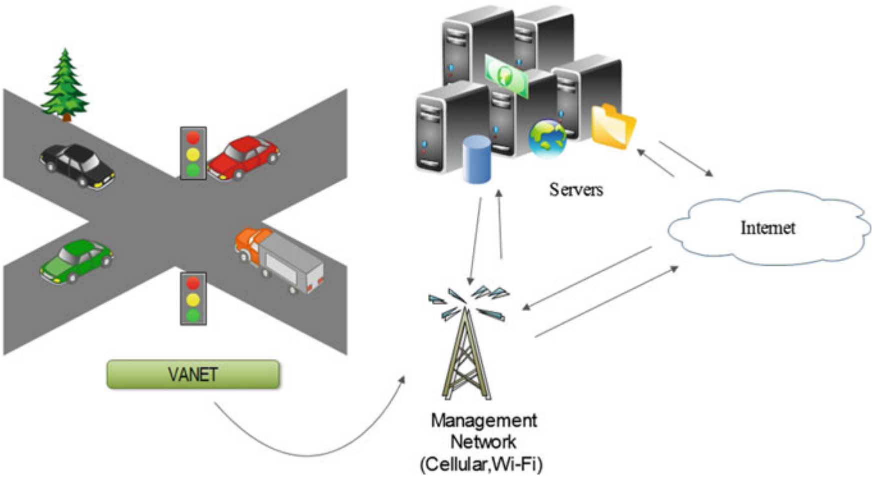

Fig. 3.5 System architecture of hybrid V-WSN framework

computing and IoT, which allows the heterogeneity of communication and expansion of the architecture in the future.

The important features of VANET-WSN architecture are worth being deeply studied. First, the proposed VANET-WSN architecture is designed to be generic compared to the ones described in Sect. 3.6. So, it supports and fits any type of VANET-WSN application. Second, it encompasses different concepts and systems. VANET-WSN allows collaboration and coordination with other systems for different purposes. For instance, when an accident occurs, vehicles share the accident position in social and personal network, so citizen avoids taking the paths that lead to the accident location. Third, it is coherent with the concept of a smart city, as it improves the citizen's quality of life by setting traffic management and allowing emergency services to reach the incident with minimum delay.

This model gathers, on one hand, the advantage of the conventional VANET, and on the other hand, it uses the computing resources of smart city devices, which can be permanent or temporarily available in the area. The temporary devices are vehicles, passengers, taxis, and bus companies. The permanent devices can be sensors deployed on roads or on buildings. This architecture is based on four layers as depicted in Fig. 3.6.

Users Layer

The users are static or mobile and could be considered as computing resource entities, which help the others to perform their service requests. They could be vehicles, passengers, and pedestrians which can establish its request through smart phone, onboard computer, GPS, Wi-Fi, etc.

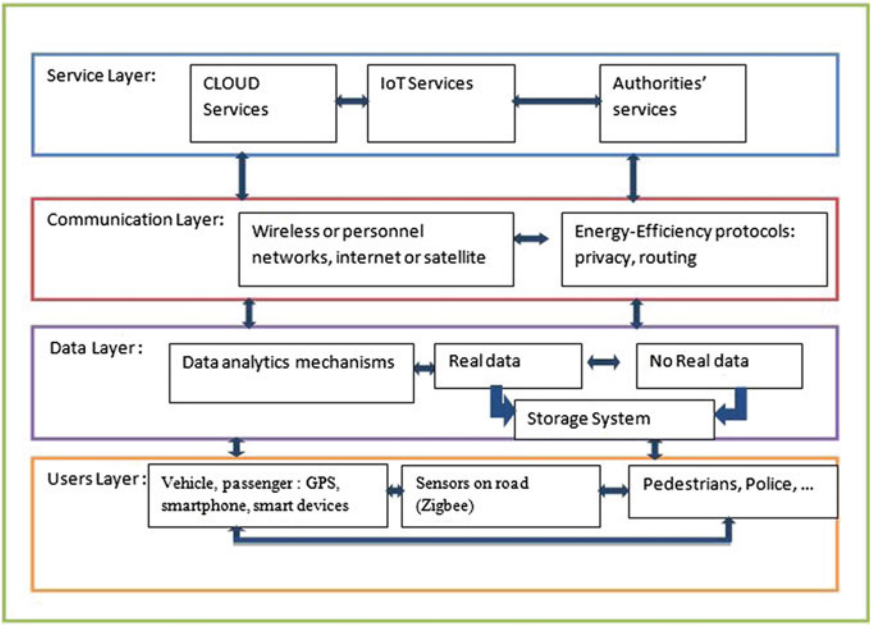

Fig. 3.6 Heterogeneous V-WSN base layer architecture

Data Layer

It applies some mechanisms that analyze and filter data on real and non-real data in order to specify the type of communication in the next layer. Also, it allows storing some important data temporary.

Communication Layer

This layer ensures a connection between users. It consists of several communication devices such as Internet, wireless networks (VANETs, WSN, 3G/4G, 5G), cellular base station, road base station, satellite, private networks, etc. Furthermore, this layer must fix security and routing protocols according to the technology used for communication.

Services Layer

This layer refers to the software and hardware delivered as services. Services proposed to the customer can be divided into three kinds of services: cloud computing services, authorities' services, and IoT services. Cloud computing services as conventional cloud can be software, platform, and infrastructure. Authorities' services can be on-site as police intervention and remotely. IoT services refer to all IoT component services, which can interact with the vehicular wireless sensor network.

3.9 Open Issues and Future Research Directions

Several directions exist for future work in the area of wireless vehicular sensor network in the smart cities environment. Meanwhile, in this kind of heterogeneous environment, the problem of communication compatibility has to be studied deeply. Moreover, wireless vehicular sensor networks open even more new opportunities for many interesting and comprehensive research issues targeting at concepts, methodologies, and techniques to support the requirement services for smart cities. First, it is very important to build a systematical development of green transportation such as cooperative mobility applications, public transport carpooling, car sharing, and so on. Also, the issues of availability, mobility, scalability, data redundancy, trajectory prediction, and throughput could guide the design, strategy determination, and parameter setting to guarantee the QoS of any service. Second, the security and privacy mechanism is also an open issue. Road infrastructures are vulnerable to a range of threats from environmental and accidental events to malicious attacks, and can lead to outages and wide disruption. For example, the use of wireless sensors deployed for traffic information collection and reporting may lead to several attacks inherited from WSNs technology and wireless multi-hop communication paradigm [18]. Also, the attacker could also launch false alarms and modify traffic lights and controllers. Third, the proposed architecture system still lacks an incentive and decision-making mechanism such as a mechanism that encourages users to participate in data sharing and choose the best services. One practical direction is to allow interoperability (of multiple technologies), standards, and latency of network architecture. The framework of vehicular wireless sensor system also produces several promising research directions. It must take into consideration various characteristics, including smart transport strategy and the performance evaluators, infrastructures, legal and regulatory policies and services models. The objectives of such a framework are to identify new challenges, quantify benefits, and evaluate performance [37].

3.10 Conclusion

The hybrid vehicular wireless sensor network in smart city is a recent paradigm that integrates VANET and WSN. It creates smart environments and may offer new services in smart cities. It helps drivers and users to reduce congestion and pollution, prevent accidents and improve road safety in smart cities.

This chapter provides a classification of different VANET-WSN applications for smart city, as well as a taxonomy classification of VANET-WSN network with respect to architecture, information, and access technologies. It presents also relevant tools and testbeds. Also, it proposes an architecture system for heterogeneous vehicular wireless sensor network and discusses open issues for the development of this network. It is expected that some research areas such as: heterogeneous communication, green hybrid VANET-WSN for smart cities, cooperative mobility applications, electric vehicle charging applications carpooling, car sharing, and on-demand taxi applications will draw more attention in the future.

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