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Enhancing Urban Traffic Management through an Internet of Vehicles Framework

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ABSTRACT

In recent years, the large number of vehicles has led to a considerable increase in urban traffic. As a result, road traffic has become one of the major problems in most major cities. Road traffic problems are congestions and accidents resulting huge loss of time, damage to property and environmental pollution. These issues explain why many research programs around the world aim to improve our transportation systems; this is indeed a difficult task because the distributed, open, dynamic and partially controllable nature of transport networks makes it a complex area. This paper deals with the problem of managing and monitoring an intelligent transportation system, especially the urban traffic system, the aim of our contribution is limiting the nuisance caused by the increase in the use of transport. Thus, better mobility means limiting the environmental impact of the pollution generated, and improving safety and conditions of people's life. In this paper, we provide a short review on the impact of integrating the Internet of Vehicles into intelligent transportation systems. Furthermore, we propose a network architecture-based Internet of Vehicles to efficiently manage and monitor urban traffic systems. Our proposition is based on several technologies, selected carefully, such as wireless sensor network, RFID radio identification technology, Fog/Edge computing, and Cloud Computing. Overall, the proposed architecture improves the coordination and the communication among the road network entities, leading to advanced transportation systems.

1. INTRODUCTION

In our daily lives, technology becomes an important aspect, as it plays a major role in all domains and offers great benefits to individuals and societies. This involves the exponential growth of the concept of the Internet of Things, which is the interconnection of billions of different types of devices and sensors, called "smart objects", so that they cooperate to meet our needs with restricted capacities in terms of energy, memory, and processing powers [1].

Moreover, Transportation systems have a strong impact on the development of our society. Effective movement of goods and people contributes to economic growth and changes our territories through a good accessibility. That is why the development in transportation is one of important factors to indicate the well-being of a country [2]. In addition, the use of New Information Technologies and Communications to improve the transportation systems become a central solution in the field. The increase in computing power and the great development of the embedded systems, as well as the quality of sophisticated sensors, have made it possible to propose more effective control mechanisms; and better consideration of operators or users, the result is so-called Intelligent Transportation Systems (ITS).

Figure. 1 Intelligent Transportation System Model

However, the European report [3] on the evaluation of research programs in transport, Intelligent Transport Systems are considered vital for designing sustainable transport systems. According to this report, through the integration of information, communication and control technologies, ITS enable authorities, operators and individuals to make better decisions. ITS concern all systems that improve the use of means of transport using a set of technologies to meet the objectives of the domain.

Whatever the functionality associated with the ITS, it is built from data captured on the network, which is received and processed by software. As a result, all the advances in communications, sensors and computing are potentially benefiting the transportation systems. For example, the development of connected or autonomous vehicles is only possible through the implementation of communications between vehicles and with a suitable infrastructure, the deployment of high-performance sensors, and significant computing capabilities.

In addition, researchers of urban traffic systems have oriented their researches to the use of the Internet of Things' technologies, which led to the apparition of new concept: The Internet of Vehicles (IoV). IoVis based on the Internet, wireless sensor networks and sensing technologies to perform both intelligent recognition of road users (who are considered as objects), monitoring, and finally the management and the real-time treatment of road traffic.

To discuss the details of this topic, we have organized the rest of our paper as follows: In the next part, we provide a concise review of IoV, comparing it with VANETs, discussing its characteristics, and the different communication modes. After that, we propose an efficient IoV architecture, based on an IoV architecture, and we explain in detail its layers and its functioning.

Finally, we present the conclusion and the perspectives of this research work.

2. PROBLEM STATEMENT

The traffic flow in urban areas continues to be problematic and the number of fatalities and accidents on roadways remains high. It is assumed that the primary cause of road issues is human error. Therefore, it is necessary to reduce the amount of human involvement in the driving process. For that reason, automotive manufacturers have attempted to create car systems that assist drivers in safety and enhanced driving is necessary.

According to Ward's research, in 2010 they were more than 1 billion in operation worldwide, and total new vehicle sales suggest that there could be up to 2 billion vehicles by 2035.The traffic remains chaotic and the number of deaths and injuries on roadways remains high [4].

Moreover, more people live in urban areas than in rural areas, and cities are expected to continue growing. The United Nations estimates that in 2050 about 66 % of the world's population would live in urban areas. Such development has a significant influence on the quality of human daily life [5].

Governments over the world have applied a variety of countermeasures in order to reduce road traffic accidents, such as laws to regulate road traffic, or automotive systems to help drivers in the driving process. Despite the wide variety of countermeasures applied by governments over the world, the transportation system still needs improvements [5].

Connected Vehicles, Intelligent Transportation Systems (ITS) along with IoT technologies, constitute the concept of the Internet of Vehicles and have the potential to release efficient and more sustainable transportation systems that are becoming increasingly important to people's daily lives [6].

Figure. 2 Traffic congestion in big cities.

3. GENERAL NOTIONS

3.1 Internet of Things (IoT)

In [7], IoT was defined as a "dynamic global network infrastructure with self-configuring capabilities based on standards and interoperable communication protocols; physical and virtual 'things' in an IoT have identities and attributes and are capable of using intelligent interfaces and being integrated as an information network".

From the viewpoint of network, the IoT is a very complicated heterogeneous network, which includes the connection between various types of networks through various communication technologies [8].

In addition, the Oxford Dictionaries offers a concise definition of the IoT: Internet of things (noun): The interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data [9]

Furthermore, the capabilities offered by the IoT can save people and organizations time and money as well as help improve decision-making and outcomes in a wide range of application areas.[10]

As well, IoT plays an important role in transportation field, such, vehicles have increasingly powerful sensing, networking, and data processing capabilities For instance, IoT technologies make it possible to track each vehicle' existing location, monitor its movement, and predict its future location. [8]

3.2 Internet Of vehicles (IoV)

It is a dynamic network, which consists of IoT enabled cars by using modern embedded and electronic devices like sensors and GPS, and integration of the information and communication systems to improve traffic flow, and to offer more effective road management and accident avoidance.

The urban traffic system has benefited from a lot of IoT applications like 'Internet of Vehicle' concept, Vehicle-to-Vehicle (V2V), and Vehicle to Infrastructure (V2I) communications, and have been transformed to a new level of interoperability, stability and efficiency, because, If vehicles communicate with each other, risks for accidents and mishaps would be very low. In addition, by using IoT technologies in the road traffic, we can monitor urban transportation systems, determine the state of traffic and pedestrian densities, identify damages and accidents, avoid collisions as needed, and optimize travel route [11].

4. IMPACTS OF TRAFFIC CONGESTION

Commonly, Traffic issues are a significant problem in urban areas, especially during rush hours [12]. According to [13] The United States spends over 836$ billion on crash-related costs, insurance premiums, and traffic law enforcement. In addition, traffic congestion costs Americans 124$ billion in direct and indirect losses, expected to reach 186$ billion by 2030. Therefore, traffic congestion in urban areas can affect Road Users' quality of traveling, society, and the economy [12].

- Road users: Traffic jams in urban roads can cause stress to vehicle users. In addition to the waste of time for motorists and passengers as well as their productive abilities. Furthermore, it can reduce the precision of calculating travel for each road user.
- Society: Traffic congestion may increase fuel consumption, and as a result, it can lead to air pollution. Unfortunately, in some cases, the congestion in urban areas can be considered a direct reason for road accidents. On another societal side, it can create late delivery of goods.
- Economy: Bottlenecks in urban roads, and according to the previous impacts, may provoke a reduction in employees' performances. Which can cause a decrease in economic growth, and will force the government to spend on enhancing the Intelligent Traffic Management Systems.

5. INTERNET OF VEHICLES AND VANETS

The use of communication technology and smart devices in vehicles has revolutionized the automotive industry. As a result, intelligent transportation systems have emerged with vehicles equipped with sensors and computers that may collect and process data for information exchange [14]. Vehicular ad hoc networks (VANETs) were introduced to enable direct communication between vehicles and infrastructure, but they face challenges such as unstable network services and limited handling of big data. In the era of 5G/B5G and the Internet of Things (IoT), VANETs are transforming into the Internet of Vehicles. Therefore, IoV aims to enhance safety, reduce congestion, and provide services through information exchange between vehicles and relevant entities. Moreover, IoV encompasses various communication models and relieson vehicle networking and intelligence technologies. These advancements expand the communication scope and potential of the IoV system [14].

5.1 Challenges in VANETS

The initial goals of VANET research technology were to ensure traffic safety [15], improve travel efficiency, and reduce pollutant emissions [16]. However, practical applications of VANET have faced challenges in commercialization. These challenges include the loss of network services when disconnected from other networks, incompatible network architectures, limitations in computing ability and storage space, and low accuracy of application services due to localized traffic data processing. To address these shortcomings, the emergence of the Internet of Vehicles offers promising prospects for the development of smart transportation systems. IoV overcomes the limitations of VANET through its heterogeneous network architecture, enabling cooperation with other communication networks. IoV is also compatible with most communication devices in daily life. The cooperation of different networks and the availability of multiple communication models (V2S, V2V, V2P, V2R, V2I) in IoV facilitate the sharing of big data, enhance the reliability of communication services, and expand the application scope of automotive communication. These advantages position IoV as a crucial development in the field [14].

5.2 Advantages of IoV

The Internet of Vehicles has attracted extensive attention from both academia and industry. It includes research areas such as intelligent transportation and telematics. The research focus of intelligent transportation is to improve travel efficiency and safety through projects such as the intelligent vehicle road system in the United States, the Eureka planning Europe, and the advanced dynamic traffic information system in Japan. The Internet of Vehicles combines mobile Internet, intelligent transportation systems, cloud computing, automotive electronics, and geographic information system to become a mixture of Internet of Things (IoT) and mobile Internet applications in the field of transportation [17]. In [13],authors have cited several advantages of the IoV, in particular, we highlight the following ones:

- IoV has transformed the road network entities into "new mobile devices". Ex: Vehicles, pedestrians, drones, etc.
- IoV creates networks that support functions such as intelligent traffic management.

- IoV consists of inter-vehicular, intra-vehicular, and vehicular mobile Internet components, enabling continuous connectivity and information exchange in vehicles.
- IoV facilitates the exchange of information between vehicles, road infrastructures, passengers, drivers, sensors, roadside units, and the Internet.
- IoV enables various services such as traffic management, road safety, healthcare apps, comfort, and infotainment.
- Communication protocols and standards like IEEE 802.11p, DMAC, VC-MAC, AODV [18], [19], DSR, and GPRS, among others, are used in IoV.
- IoV differs from Intelligent Transportation Systems by emphasizing information exchange among vehicles, humans, and road infrastructures.
- Estimated benefits per vehicle per year include savings on insurance rates, operation costs, and time spent in traffic for vehicle users.
- Society benefits from decreased accidents, traffic jam control, and reduced CO2 emissions.
- IoV has the potential to create around 400,000 new jobs in the United States.
- The global market size for IoV components is estimated to reach 115.26 billion Euros by 2020, according to the European Union.

6. CHARACTERISTICS OF IOV

Furthermore, the Internet of Vehicles environments illustrates a multitude of significant characteristics that contribute to their unique nature and functionality. In particular, we highlight the following key aspects [20]:

- **Dynamic topology and non-uniform node distribution:** The IoV network is composed of various entities. One prominent characteristic of this network is the mobility of vehicles, pedestrians, cyclists, drones, and mobile radars, which are constantly changing their locations, speed, and direction. Furthermore, the distribution of these entities in an IoV network depends on several factors, such as road conditions and driving habits [20]. This mobility aspect requires efficient communication and coordination mechanisms to ensure seamless connectivity and accurate data exchange, even in high-speed scenarios.
- **Heterogeneity:** IoV encompasses diverse vehicles with different types of communication technologies, such as DSRC, 4G/LTE, WiFi, and Zigbee... The heterogeneous nature of IoV enables compatibility and interoperability between different vehicles and infrastructures [20].
- **Granularity:** In the IoV, vehicles on the road can be categorized into subsets called Sub-IoVs, which operate at a more localized level and have lower granularities. By using different granularities, the IoV enables flexible and scalable data collection and analysis for intelligent transportation systems [20].
- **Scalability:** The IoV network is massive, with a large number of vehicles and infrastructure; therefore, IoV should be scalable rapidly, to handle the growing volume of data, the number of connected devices, and the complexity of IoV applications [20].
- **Big data and high processing capability:** In IoV networks, vehicles, sensors, road infrastructure, drivers, pedestrians, and all other entities continuously generate huge amounts of data. Therefore, it should be collected, aggregated, processed, and analyzed in real-time to make decisions and extract valuable insights for improving transportation efficiency [21]. Furthermore, data processing and decision-making are assured by the fog/edge servers for rapid responses and by the cloud servers for general and large-scale decisions.

6.2 Communication modes in IoV

The Internet of Vehicles is a considerable shift in vehicle networking, leading to the development of intelligent transportation systems. IoV is a heterogeneous network consisting of various communication modes illustrated in Figure 3:

- **Vehicle-to-Vehicle (V2V):**inter-vehicle communication allows vehicles on the road to exchange information, messages, and even sensor data. Such communication not only ensures road safety but also enables cooperative driving by sharing details like location, speed, acceleration, and destination of each vehicle.
- **Vehicle-to-Person (V2P):** it enables vehicles to communicate with drivers, pedestrians, cyclists, and traffic police personnel, providing them with important information to enhance safety and improve overall traffic management.
- **Vehicle-to-Roadside (V2R):** the exchange of information or messages between vehicles and roadside units, like traffic lights, road signs, toll booths, parking systems, cameras, and radars.
- **Vehicle-to-Infrastructure (V2I):** it represents the communication between vehicles and the infrastructure responsible for high processing capabilities via WiFi or cellular networks like LTE/4G/5G [14].
- **Vehicle-to-Sensors (V2S):** this communication enables vehicles to interact with various types of sensors located on both sides of the road such as radar sensors, Inductive Loop Detectors, Ultrasonic sensors, microwave sensors, infrared sensors, and acoustic sensors [22].

6.3 IoV application in transportation systems

The Internet of Vehicles has attracted widespread attention in the market and has applications in different fields of transportation, which can be divided into the following categories [20], [21], [23]:

- **Healthcare applications:** The main objective of this type of IoV application is to decrease road accidents, and as a consequence, road deaths, for instance: Intersection collision warning [21]. In addition to real-time communication between vehicles and healthcare professionals. In emergencies, vehicles equipped with medical devices can establish a connection with doctors or specialists who can remotely provide guidance and instructions for immediate medical intervention. In addition, Vehicles can be equipped with sensors and wearable devices to monitor the health parameters of passengers or drivers.

- **Safety-related application:** Vehicles diagnostics and maintenance [21], hazardous location notification, and collision warning systems were designed to minimize the number of accidents in IoV networks.
- **Traffic efficiency application:** it offers enhanced route guidance and navigation, to improve road traffic management and advance the field of traffic routing, like in a previous research work [22].
- **Comfort-related applications:** smart parking systems [24]and energy supply stations.

7. METHODOLOGY

7.1 IoT Architectures' Background

In [25], authors surveyed existing IoT architectures, which are three-layer architecture, Middleware-based architecture, Service Oriented Architecture (SOA), and Five-layer architecture. Furthermore, they marked that the five-layer architecture is the most appropriate model for IoT applications, due to its simplicity, by the way, this later consists of five layers : 1. Objects layer or perception layer, which contains physical components like sensors, actuators, 2. Objects Abstraction layer, by using this layer we transfer data generated by Objects layer over WiFi, GSM... 3. Service management layer, which processes data, makes decisions, and delivers services over network protocols. 4. Application layer, that provides high quality smart services to meet customer's needs, and 5. The Business layer that supports decision-making based on big-data analysis.

Authors of [26] presented two types of IoT architectures; the basic Three-layer architecture, it consists of perception or sensor layer, Network layer and application layer, and the four-layer SoA-based IoT architecture, which is composed of Perception layer, Network layer, Service layer, and Application layer, service layer is made of service discovery, service composition, service management, and interfaces. According to the authors, the service-oriented architecture is more flexible and generic, because a service layer is developed between network layer and application layer to provide the data services in IoT architectures like data aggregation and processing in network layer, and data mining, data analytics in application layer. After that, they introduced the relevant enabling technologies and challenges of each layer, and they token the four-layer SoA-based IoT architecture as an example.

In [27], authors proposed a four-layer architecture for future heterogeneous IoT, which contains Sensing layer, Networking layer, Cloud computing, and Application layer, we explain each layer with more details in the next part of the paper.

7.2 The proposed IoV architecture

In [27], the authors propose a four-layer architecture for the future Internet of Things; we combine this architecture with the concept of fog/edge computing, and we add a novel layer to this architecture, which is the edge servers' layer. Then, we adapt this architecture to be destined for road traffic systems; in this section, we explain our architecture in more detail.

Layers of the proposed architecture

First, we present the layers of our architecture illustrated in Figure 3:

- Sensing layer: This layer represents the physical sensors, actuators, and RFID tags that aim to capture, collect, and transmit information [25]. A large number of sensors are deployed in the monitoring area [27], which is in our case the urban road; we use sensors to collect data about the state of the road (if it is congested, or there is an accident or a fire in the road). From vehicles that are equipped with RFID tags, and pedestrians who have all smart phones in their possession, or swatches connected to the internet. Those sensors send the captured data to the sink node, which we call the master node; we will explain its role in the Fog/Edge computing layer.

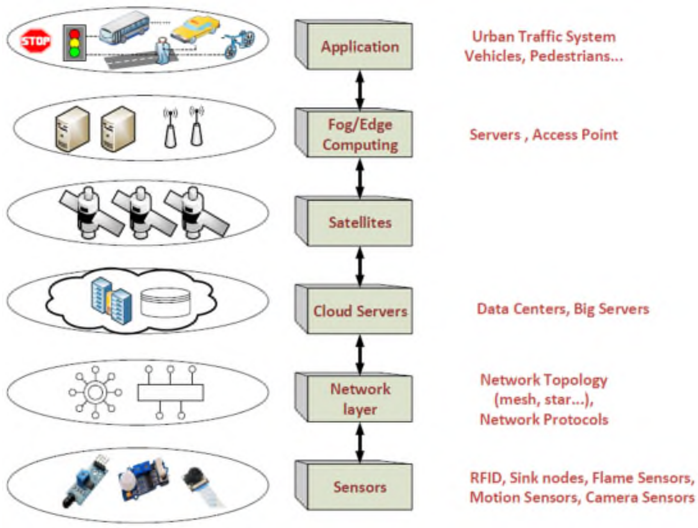

Figure. 3: The proposed architecture's layers.

- Network layer: In this layer, we implement network protocols, and the corresponding topologies like star topology, tree topology, mesh topology, or hybrid topology, in order to forward data packets from source node to destination node [27]. However, we consider self-organizing network protocols, because we need more robustness and efficiency in the construction of network topology, like the IPv6 routing protocol "RPL", which is a distance vector routing protocol designed by the Internet Engineering Task Force IETF, for Low Power and Lossy Networks.
- Cloud layer: This layer is very important to handle the tremendous amount of data collected, and transmitted by other layers to cloud servers and big data centers,

to be processed, stored, and to make decisions based on data analysis [27], [26], thanks to the powerful analytical computing capacities that have cloud servers. Cloud computing is now a mature technology used to create, store, and use data over the Internet. Although, when amassive amount of data need to be stored, processed, and analyzed efficiently in data centers and cloud servers, a new technology appears to fulfill the gap, which is Fog/Edge computing, to extend cloud computing to be closer to the network of things [26].

- Satellite Sub-layer: To transmit data between Edge Servers and Cloud data centers and servers, we use Satellites, to gain time, throughput, and energy.
- Fog/Edge Computing layer: In this layer, we have two types of devices, the Master Nodes, and the Edge servers. We can use Edge servers for insuring processing, and storage and making decisions near the network, instead of doing all the computations in the cloud servers, hence, Edge computing has faster response and greater quality than cloud computing [26], especially, when we are faced to a real-time application like road traffic. We update datacenters of the cloud once a day, at night, to minimize disruptions during peak hours, ensure that resources are available at night when fewer users are active, and reduce competition for bandwidth; on the other hand, we transmit data from master nodes to Edge Servers several times and periodically in the journey, because we can place some types of data for further computations and analysis, however, the high priority data, we address immediately to the closest Edge server, to ensure the real-time property of the road traffic system. The master node is an access point with good processing, energy, and transmission capacities, if we compare it with the road sensors, its role is to 1- receive the data collected by all the sensors near it, i.e. In the same area. 2- After that, it makes some calculations and data aggregations to reduce the big amount of the collected data, because and without a doubt, we will find a lot of redundancy, because, the sensors are in the same region and they will capture sometimes the same information.
- Application layer: The application layer responds tousers' needs, by providing them the corresponding services[25], for instance, a car driver needs to know if thisroad is congested or not, he uses our application to get thebest response. Our application here is urban road traffic management, which includes vehicles, pedestrians with their smartphones, or smart watches, road sensors, and other smart devices that are connected as objects in the network, delivered data is used to ensure the real-time management of the urban road traffic. Edge and cloud servers can manage and monitor remotely objects based on data analytics and visualization [27].

7.3 The functioning of the proposed architecture

Our Architecture is hybrid, in terms of connecting objects in the IoT network, which means that objects cooperate with each other and exchange information on traffic; and hierarchical, because objects connect with the master node to transfer the data captured by sensors to the Edge Servers, in addition, data processing in edge servers will be sent for processing and make decisions to the cloud centers, as it's illustrated in Figure 4.

In each vehicle, we find a GPS (Global Positioning System); this later is responsible for receiving important data like location, time, and weather conditions from satellites [2]. In addition, we have RFID chips; their role is to exchange information with other vehicles and pedestrians and with road sensors using Zigbee IEEE 802.15.4. Road sensors are responsible for capturing road traffic data, from vehicles and pedestrians, these data tell us if there are congestions, accidents, or flames. . .

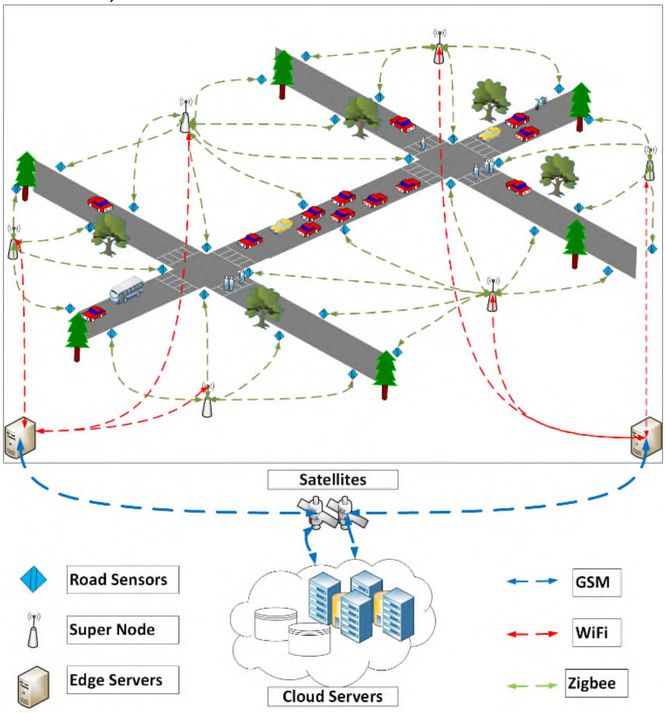

Figure.4: The proposed architecture of the ITS-based IoV

After that, they transmit the collectingdata to the master node via WiFi IEEE 802.11. The masternode consists of communication and data treatment modules;the communication part is a wireless antenna, which is responsiblefor receiving and decoding the transmitted data packetsfrom the road sensors or the edge servers. Furthermore, thedata treatment module is used to do some data aggregationon the data received from the road sensors, because therewill be certainly redundancies, in addition, mechanisms ofdata aggregation aim to reduce the amount of transmissiondata and energy consumption [2]. The aggregated data areforwarded to the nearest edge server via GPRS (General PacketRadio Service), which is a cellular communication protocol,named 2.5 Generation (2.5 G), it means that is between thesecond generation and the third generation of GSM (GlobalSystem for Mobile communication). Each Edge Server makeprocessing and calculations on data transmitted from Masternodes, make decisions, and preventions, to raise alarm todrivers or pedestrians to avert them if there is congestion,accidents,

and flames. . . to avoid more damage on the road;this process is repeating during all day long. Edge servershave a big power of storage and processing to make betterdecisions to ameliorate the quality of transportation in urbanareas, they are an intermediary between Cloud servers anddata centers, and sensor networks on the road. Processed data,decision-making, and preventions will be sent to Cloud serversthrough satellites, we use 4G to transfer data. Why use theseexisting protocols? We use any available network within therange, to insuring communication between components in an
IoT system, which seems to be a better solution [2]. Like here
in our case, we use WiFi, and cellular networks like GPRSand 4G LTE, which are pre-existing network architectures,in order to avoid implementing new infrastructures. In Cloudcenters, we make global and heavy operations, due to the bigcapacity of processing and storage, we use virtualization anddata analytics to make better decisions and preventions andstore data to use for improving the urban road traffic system.

CONCLUSIONS

The Internet of Vehicles is an important concept in the field of transportation and autonomous driving. It connects people, vehicles, and road infrastructure. It has gained commercial and economic interest and attracted the attention of researchers in the transportation area due to advancements in computation and communication technologies. This paper provides a short review of the impact of IoV on intelligent transportation systems by discussing problems and major issues in road systems, and the challenges in VANETS. After that, we present the key aspects of the IoV ecosystems: the most important characteristics, advantages, and modes of communication and the applications of IoV in transportation systems. Then, we present the IoV-based architecture. Therefore, the proposed architectureis generic and flexible for all urban traffic systems and can be applicable in the real world, because we bring together current and existing IoV and IoT technologies. The proposed architecture is global; we work to detail it more and more, using IoT and IoV technologies, and to implement its layers in the near future; once successfully implemented, the reduction of damages, collisions, congestion, and pollution in the urban road traffic will certainly benefit the quality of people's lives in urban areas.

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