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Intelligent transportation systems for sustainable smart cities

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ABSTRACT

Intelligent Transportation Systems are rapidly expanding to meet the growing demand for safer, more efficient, and sustainable transportation solutions. These systems encompass various applications, from traffic management and control to autonomous vehicles, aiming to enhance mobility experiences while addressing urbanization challenges. This paper examines key components of Intelligent Transportation Systems, including Vehicular Ad-hoc Networks, Intelligent Traffic Lights, Virtual Traffic Lights, and Mobility Prediction, emphasizing their role in improving transportation efficiency, safety, and sustainability. It explores recent advancements in communication systems that enable real-time Intelligent Transportation Systems operations, contributing to the realization of environmentally friendly smart cities.Moreover, the paper addresses security challenges associated with Intelligent Transportation Systems deployment, particularly concerning public transit privacy, and presents case studies illustrating the benefits of Intelligent Transportation Systems integration in specific urban areas, emphasizing its role in fostering Sustainable Smart Cities. Additionally, it examines proactive initiatives by automotive manufacturers in adhering to Intelligent Transportation Systems standards, ensuring mutual benefits for drivers and urban centers.

1. Introduction

Intelligent Transportation Systems (ITSs) have emerged as a revolutionary force in modern transportation's fast-expanding environment, fundamentally changing how we convey people and things. They combine cutting-edge technology, data analytics, and communication systems that aim to improve transportation networks' effectiveness, security, and environmental friendliness [1].

ITS utilizes state of the art information and communication technology to enhance several areas of transportation, including traffic management, vehicle operation and public transit systems. ITS seeks to alleviate traffic congestion, decrease journey durations, improve safety, and limit environmental effects using real-time data, sensor networks, and intelligent algorithms [1,2].

The scope of ITS is extensive, covering a wide range of applications, including intelligent traffic signal systems, autonomous vehicle technology, dynamic route planning, electronic toll collection, and real-time public transit tracking. These advancements not only enhance everyday transportation for individuals but also contribute to wider social objectives such as energy conservation, less emissions, and improved urban planning.

With the ongoing acceleration of urbanization and increasing demand for efficient transportation, ITS plays a crucial role in determining the future of mobility. Global governments, corporations, and researchers are allocating resources toward implementing ITS technologies to establish more intelligent, interconnected, and environmentally friendly transportation ecosystems.

The advent of technologies such as the Internet of Things (IoT) and 5 G communications in recent years has accelerated the adoption of ITS [1]. Intelligent Traffic Lights (ITL), Virtual Traffic Lights (VTL), Vehicular Ad-hoc Networks (VANETs) and Mobility Prediction are prominent ITS applications. These are intended to improve traffic flow and reduce congestion [2].

This paper is dedicated to exploring the crucial role of ITS applications in shaping Sustainable Smart Cities. In Section 2, various forms of VANETs are described, alongside discussions on implementing ITL, VTL, and Mobility Prediction within smart urban environments. Section 3 delves into communication technologies like 5 G, pivotal for enabling real-time response and operation of ITS, while emphasizing the primary components essential for constructing and interconnecting VANETs,

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including sensors, AI cameras, Roadside Units (RSUs), and vehicle On-Board Units (OBUs).

Additionally, Section 4 sheds light on the security challenges associated with deploying ITS, posing implications for the privacy of public transit. Section 5 delves into case studies of specific urban areas, illustrating the benefits derived from ITS integration and its pivotal role in fostering Sustainable Smart Cities. Intelligent transportation not only enhances driving experiences, road safety, and traffic management but also yields significant sustainability benefits by reducing CO2 emissions and other harmful pollutants [3,4].

Furthermore, the latter part of Section 5 examines the proactive initiatives of automotive manufacturers in adhering to ITS standards, ensuring mutual benefits for drivers and urban centers. Each subsection within Section 5 is accompanied by tables summarizing the ITS technologies adopted by cities and automotive manufacturers, along with their corresponding achievements. The paper concludes in Sections 6 and 7, succinctly encapsulating the main themes discussed and suggesting future research avenues and improvements to fortify the transportation infrastructure of smart cities.

2. ITS technologies

Vehicular Ad-hoc Networks (VANETs), Intelligent traffic lights (ITL), Virtual Traffic Lights (VTL), and Mobility Prediction are essential systems that fall below the umbrella of Intelligent Transportation Systems. They are the primary devices employed to complete the smart city revolution. ITS is crucial for realizing smart cities since it helps minimize vehicle idle time, prioritizes emergency vehicles, shortens emergency response time, improves traffic efficiency, prevents unexpected collisions, and reduces carbon emissions. Integrating 5 G real-time communications within these technologies can further boost their efficacy.

It has been demonstrated via research that ITS-based effective traffic management systems have the potential to drastically cut travel times by as much as 25%, resulting in significant time savings for commuters. Through the optimization of the timing of traffic lights, intelligent traffic management systems have the potential to reduce energy consumption and emissions of greenhouse gases by around 15–20 %. According to the findings of a survey that was carried out in urban areas [5], intelligent traffic management systems can reduce the number of accidents that occur in metropolitan areas by as much as 20 %. This is accomplished by improving the coordination of traffic flow and the management of incidents in real-time [5].

2.1. Vehicular Ad-hoc networks (VANETs)

Adopting Internet of Vehicle (IoV) ecosystem for smart cities will enable the collection and sharing of information about cars, roads, infrastructure, buildings, and more. The VANETS field is vast in that it is divided into various subcategories describing how the process of VANETs performs in Smart Cities. Vehicle to Vehicle (V2V) and Vehicle to infrastructure (V2I) communications are the core functionality of VANETs. In V2V communication, vehicles communicate with each other directly to exchange information such as location, speed, and direction. This data is essential for developing cooperative safety apps to help avoid accidents and minimize traffic congestion [6]. The second primary type is (V2I), which enables vehicles to communicate with traffic lights, sensors, and cameras to enhance safety and traffic flow. Those types of communication can provide drivers with real-time information about road conditions, traffic congestion, and accidents [6–8]. Vehicle-to-Server (V2S) is a subset of (V2I) that involves communication between a vehicle and a remote server and is commonly used for real-time traffic monitoring and route optimization. Vehicle-to-House (V2H) communication connects cars with home equipment, including charging stations and intelligent appliances. It can also charge electric vehicles, warm or chill them, and operate home automation tasks like turning on lights or opening the front doors. Vehicle-to-cloud (V2C) communication establishes a connection between the vehicle and cloud-based services by exchanging data collected from the vehicle's sensors, navigation and other smart equipment about car status, road condition sent to the cloud for analysis and then sent back to the vehicle in the form of valuable accurate time information as traffic condition and personalized route planning [8]. V2N is used to connect the vehicle with the external network as a cellular network to access the features of the cloud-based services and connect with intelligent traffic lights and traffic management systems; it is also used to receive real-time updates about traffic, navigation, and weather conditions. Figs. 1 and 2 below illustrate the various types of VANETs, including both common and essential ones, and show a scenario of how vehicles communicate together.

Vehicle-to-pedestrian (V2P) communication proves highly advantageous at intersections, as depicted in Fig. 3. These figures illustrate real-time warning messages transmitted to both pedestrians' smartphones and vehicle screens via a cellular network. This communication system operates effectively when a vehicle approaches an intersection or crossroad, and a pedestrian unexpectedly appears on the road without noticing the approaching vehicle traveling at high speed. By facilitating such timely alerts, V2P communication significantly mitigates the risk of car accidents [6–10].

V2X combines all the essential types of VANETs (V2V, V2I, V2P and V2N) to work together to make the vehicle connect easily with everything around it as access network, exchange data from the cloud, receive notifications and warning messages about pedestrians crossing the streets suddenly, communicate with vehicles on the street by exchanging information about speed, vehicle status, and directions, get connected with road infrastructure as Intelligent traffic lights, sensors to have real-time updates about the road congestion and traffic flow. These features and data help the vehicle perform auto-driving efficiently.

1.1 Intelligent Traffic lights (ITL)

ITLs are crucial to ITs because they manage traffic movement and increase road safety. ITLs are traffic lights that improve traffic movement and lessen congestion using real-time traffic data and sophisticated algorithms [11]. They gather real-time traffic data using various equipment including cameras, radars and sensors [12]. Advanced algorithms are then used to analyze the collected data, determining the ideal scheduling for traffic lights based on variables like traffic volume, congestion, and pedestrian movement. This is contrary to conventional traffic lights, which are only set to change color phases after a predetermined time [13]. For instance, ITLs can adjust the timing of traffic lights to ease congestion in heavy traffic. This leads to decreased idling time and reduced CO_2 emissions from vehicles. ITLs can also identify bicycles and walkers and give them secure crossing periods, lowering the rate of accidents [14].

Additionally, ITL can control the traffic in such a way as to enable emergency vehicles to pass without being delayed. It detects emergency vehicles and changes their condition to green, thus allowing them to pass swiftly. ITLs could also lessen the collisions brought on by dodging red lights. ITLs can decrease the time that vehicles must wait at red lights by optimizing the timing of traffic signs using cutting-edge algorithms. This reduces the desire to jump red lights, which may eventually result in fewer accidents [15].

The procedure will vastly improve with employing 5 G and IoT. Because 5 G networks have minimal latency, traffic signals can communicate with each other and with other linked devices in real-time. This enables traffic lights to react to changes in traffic patterns more rapidly and modify their signals appropriately. For example, suppose a traffic light notices a traffic buildup on a specific route. In that case, it can change the signal timing to enable more cars to travel through. The use of 5 G empowers the utilization of more sophisticated sensors and cameras to record real-time data on road conditions [11–15].

Sensors placed on the road surface can identify the existence of cars. To determine the existence and movement of vehicles, these devices can

Fig. 1. Vehicles communication in Smart cities [5].

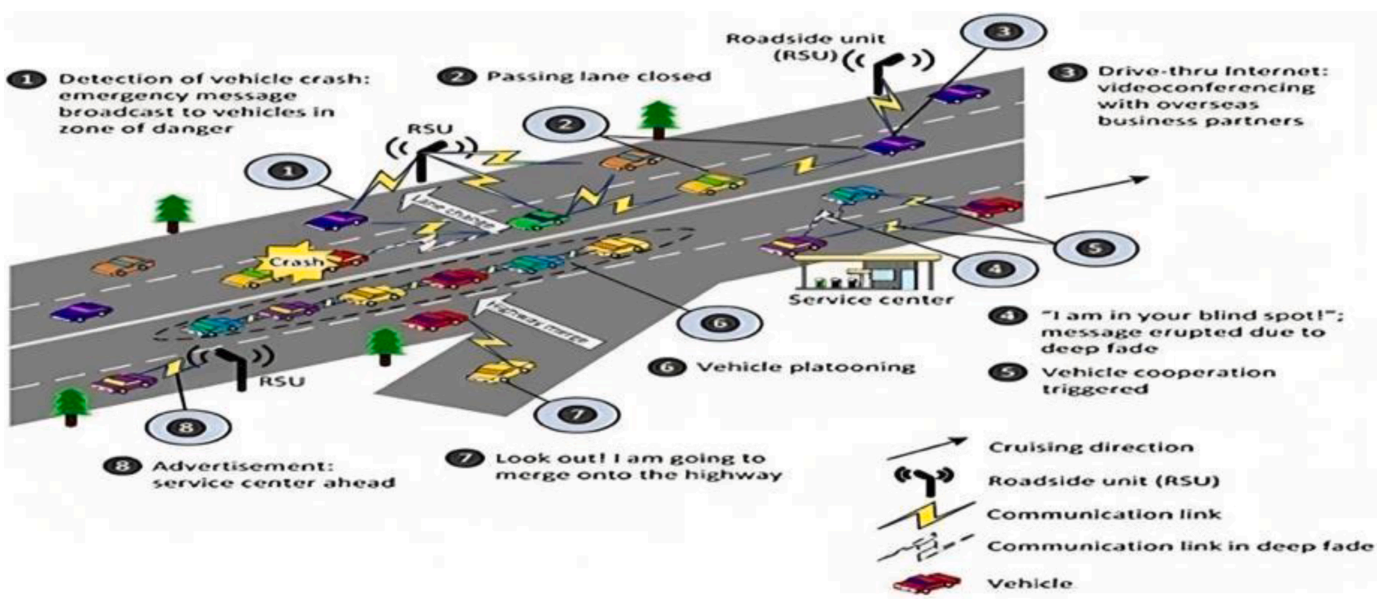

Fig. 2. A vehicle communication scenario [10].

employ various technologies such as inductive loops, radar, or infrared. Cameras can also be placed to record pictures of the junction and evaluate them using computer vision algorithms. These algorithms can recognize the existence of vehicles, distinguish their class (e.g., automobile, truck, bicycle, emergency vehicle), and monitor their movement. IoT devices, such as GPS-enabled automobiles or cell phones, can also provide information on the position and movement of vehicles near the junction. All this data is gathered and analyzed in real time using edge judgments based on current traffic circumstances.

ITLs can correctly detect the number of cars in a junction and change their signal settings by merging data from these sources. For example, if traffic signals notice a large amount of traffic coming from one direction, they can change the signal speed to give that route a greener time, reducing vehicle wait time [15,16]. The primary idea is that ITLs use real-time data from numerous sources to make more informed choices [14–17].

1.2 Virtual Traffic lights (VTL)

The invention of the VTLs has dramatically improved the ITS with the help of 5 G and Road infrastructure (cameras, sensors, etc.) to detect vehicles and project virtual signals onto the road, which OBUs detect in equipped vehicles to inform drivers about road conditions [18]. For example, when there is a car moving straight in the intersection, and there is another car coming from the left or right at a higher speed, the VTL detects this situation and sends a stop warning message in real time to the OBU implemented inside the vehicle; if the slower vehicle fails to stop, the VTL system can alert the driver through OBU or directly to the vehicle's automated systems, triggering an automatic braking system to prevent a collision, the same thing also happens for pedestrians crossing the street in an intersection. VTL can also prioritize emergency vehicles, reducing emergency response times [19]. Furthermore, using VTL in intersections can reduce congestion, improve traffic flow, increase safety, and minimize idling time at intersections. VTL is a fantastic tool for enhancing driving safety, especially at road junctions in residential areas with no actual traffic lights because of the constrained width of the streets.

OBUs are critical to the success of VTLs. They are devices installed in the car that communicate with other vehicles using the same technology to provide data about traffic conditions, speed, and additional relevant

Fig. 3. A warning message sent to both the pedestrian and car [9].

information, assisting drivers in making the right choice. Vehicles and virtual traffic signals can communicate in real time thanks to 5 G technology's high-speed, low-latency connection, which allows the VTL to give vehicles more precise and current information, enhancing safety and easing congestion [19].

1.3 Mobility Prediction

Mobility prediction plays a crucial role in developing smart cities and VANETs. It has received considerable attention since it can speed up the development of autonomous vehicles, improve traffic management, and increase safety while advancing the development of smart cities. The progress of this technology, which will make our roads safer and more user-friendly, will have a tremendous impact on the future of transportation [20,21].

The critical objective of mobility prediction techniques is to predict vehicle movement patterns inside a network. Various algorithms and data sources are used to predict future vehicle placements and behavior on the road. This forecast is supported by previous information, the current flow of traffic, and real-time sensor data from moving cars and the roadside [22]. The objective is to forecast where automobiles will be in the near future accurately. The impact of mobility prediction on vehicular networks is substantial, as it can help improve the efficiency of the various aspects of the smart city.

Additionally, mobility prediction positively impacts Traffic Management; it can help reduce traffic congestion by allowing intelligent traffic management systems to anticipate and proactively respond to traffic bottlenecks in real time. For example, suppose a system predicts a traffic jam forming on a particular route. In that case, it can suggest alternate routes to drivers, reducing congestion, travel time, fuel costs, and air pollution. On the other hand, Predicting the movement of vehicles can aid in optimizing traffic light synchronization [23]. When the system knows that a group of vehicles is approaching an intersection, it can adjust the timing of traffic lights to ensure smoother traffic flow, reducing waiting times and fuel consumption [21]. Moreover, mobility prediction can enable dynamic lane assignment on highways. For instance, if a system anticipates a high volume of traffic entering a particular lane, it can redirect vehicles to less congested lanes, which leads to balancing the traffic load and preventing traffic jams.

From a safety point of view, predicting the behavior of vehicles can help prevent accidents. Advanced Driver Assistance Systems (ADAS) can use mobility prediction to alert drivers to potential collision risks, enabling them to take corrective actions when moving from one lane to another [23,24]. Mobility prediction is also crucial for developing and deploying Autonomous Vehicles (AVs). Self-driving cars rely heavily on predicting the movements of other vehicles and pedestrians to make safe driving decisions. These predictions help AVs navigate complex traffic scenarios, make lane changes, and merge into highways seamlessly.

Mobility prediction can assist emergency services in responding more effectively to accidents and emergencies. By anticipating the location and severity of incidents, responders can be dispatched more efficiently, potentially saving lives. Mobile and vehicular data delivery will benefit the most from mobility prediction. In the rapidly evolving landscape of mobile networks, the ability to predict user mobility and adapt data delivery accordingly has become increasingly vital. Mobility prediction, which involves forecasting the movement patterns of mobile users, has a profound impact on the efficiency, reliability, and overall performance of data delivery and exchange within these networks.

Another advantage of mobility prediction is that it can contribute to improving the handover process in mobile networks, where users switch from one base station to another for better service. Typically, handovers are based on the received signal strength, but frequent handovers can lead to service disruptions and connection loss. However, predicting the user movements and future locations, can enhance the handover process, such as reducing the number of handovers, decreasing connections and calls drop rate, minimizing handover latency and improving network performance [25,26]. This prediction will enhance the Quality of Service (QoS) and optimize network resource allocation to achieve seamless handovers and ensure uninterrupted data delivery. Also, within the vehicular network prediction of vehicle's mobility and future locations or the trajectory of the mobile vehicle, it can lead to better resources allocation, data delivery and exchange of information between the vehicles in smart cities.

A trajectory is defined as the route or the path that a moving object follows in 3-D space as a function of time [27]. It can be described mathematically by a polynomial where the user's (vehicle) direction of movement can be determined by the one ordered derivative of the trajectory polynomial. The trajectory can also be determined by predicting the future location based on data set of previous trajectories [28]. If the network can predict the user needs on the move and reserves the required radio resource in all cells along the trajectory, the communication efficiency can be significantly improved [29].

Another application of mobility prediction is the allocation of resources in crowded areas. For instance, if a network anticipates a high concentration of users in a particular area, it can allocate additional bandwidth and computing resources to ensure smooth data delivery during peak times.

Efficient data caching, prefetching and content delivery can be achieved by mobility prediction. Mobile networks often employ content caching and prefetching techniques to reduce latency and data usage. Mobility prediction allows networks to cache and pre-fetch content more intelligently by predicting which content a user is likely to request based on their location and historical behavior. This can significantly reduce the time it takes to deliver content to users. Moreover, predictive caching and prefetching also help reduce the overall data traffic on the network. By delivering content to users before they request it, networks can avoid unnecessary data transfers, saving bandwidth and reducing congestion [30]. mobility-aware precaching strategy is achieving a high prediction accuracy and supporting seamless mobility handover [31]

Other advantages of mobility prediction include improving user experience, network efficiency and cost reduction as it enables mobile networks to offer personalized services to users. For example, based on a user's predicted location and preferences, a network can provide tailored recommendations, advertisements, and content, enhancing the user experience and engagement. It can also help in predicting the QoS, networks can proactively optimize the quality of service for individual users based on their predicted mobility patterns. For example, if a user is predicted to be in a location with poor network coverage, the network can allocate additional resources to maintain a high-quality connection.

Proactive techniques and mobility prediction can contribute on reducing energy consumption by powering down or adjusting the operation mode to sleeping mode of certain network components during periods of low predicted user activity thus operators can reduce their carbon footprint and operational costs.

With its diverse fields of applications that include traffic management, transportation planning, and location-based services, mobility prediction has gained a lot of attention by modern researchers as accurate predictions of mobility patterns are crucial for optimizing resource allocation, mitigating traffic congestion, and improving decision-making in various sectors.

Due to its applications in diverse fields, mobility prediction can be carried out using various methods depending on the intended application, the available data used for the perdition, and the level of accuracy required for the mobility prediction process. Statistical models, machine learning techniques, time-geography, and space syntax have all contributed to enhancing our understanding of mobility and improving prediction accuracy. The discussion below provides an overview of the key approaches and advancements in forecasting the movement or location of individuals, vehicles, and objects and highlights some of the prominent methods and research in this field.

1.3.1 Mobility prediction techniques

1. Statistical Models;

Time Series Analysis and Regression Analysis: This method involves analyzing a set of historical data to identify patterns or trends in mobility using a short time query of data [28]. Techniques like autoregressive integrated moving average (ARIMA) models [32] can be used for time series forecasting. Regression models can be employed to establish relationships between mobility variables and predictor variables, such as time, weather conditions, or economic factors.

2. Machine Learning;

Machine learning methods have become increasingly popular for mobility prediction [33]. These methods can be classified into several classes includes supervised Learning, unsupervised Learning, Recurrent Neural Networks (RNNs) and Convolutional Neural Networks (CNNs).

Supervised Algorithms like decision trees, random forests, and gradient boosting can be used to predict mobility based on labeled data and classification of the spatial trajectories [34]. While Unsupervised Learning can help identify groups of similar mobility patterns or hotspots.

Recurrent Neural Networks (RNNs) are useful for sequential data, making them suitable for predicting mobility over time [35]. Long Short-Term Memory (LSTM) networks are a popular choice for this. Convolutional Neural Networks (CNNs): CNNs can be used for predicting mobility in spatial contexts, such as object detection and tracking in images or video data.

3. Time-Geography and Space Syntax;

Mapping geographical Data to mobility parameters such as time, speed, acceleration and direction of movement can be used to identify both temporal and spatial aspects of mobility [36]. It helps in understanding and predicting human movement based on constraints and opportunities in time and space. Many available tools, such as geographic Information System (GIS) tools, can be used to analyze and predict mobility patterns based on geographic data.

4. Cellular Data and GPS Tracking;

Mobile phones and GPS devices generate large amounts of location data. Analyzing this data can provide real-time insights into mobility patterns and allow for predictive modeling.

5. Hybrid Models.

Combining multiple methods and data sources can often lead to more accurate predictions. For example, combining statistical models with machine learning or using GPS data in conjunction with social network analysis.

3. Communication Technologies that enable efficient ITS

Smart cities and intelligent transportation systems are primarily dependent on reliable communication technologies. Cities face tremendous issues as they grow in population, such as transportation congestion, energy usage, and pollution. They are turning to smart technology to solve these concerns, combining diverse systems and sensors to allow real-time data collection, analysis, and decision-making. Nowadays, ITS has gained popularity not only because it integrates various communication technologies to optimize traffic flow but also because it minimizes congestion and improves overall road safety. This section overviews the most important and commonly used communication technologies, such as IEEE protocols, C-V2X, LoRaWAN & 5 G.

3.1. IEEE Standard protocols

IEEE communication protocols are critical in ITS because they allow efficient and secure communication between cars, infrastructure, and operators. As technology advances, we may anticipate the development of new and creative IEEE protocols to serve the next generation of ITS applications.

IEEE 802.11p, known as Wireless Access in Automotive Contexts, is a standard for wireless communication systems in vehicular environments (WAVE). It is specially developed for V2V and V2I communication in ITS. It employs Orthogonal Frequency Division Multiplexing (OFDM) modulation and operates in the 5.9 GHz frequency spectrum. It can transfer data at speeds of up to 27 Mbps, which is suitable for sending safety-critical information, including collision warnings, road danger notifications, and emergency vehicle alerts [36]. Measures are also included to assure reliable and timely message transmission, especially in high-speed vehicle contexts with potentially high interference levels. In addition, it has a channel-switching mechanism to minimize interference from other wireless systems, as well as mechanisms for prioritizing safety-essential signals over less important ones. It is essential for enhancing road safety and allowing sophisticated ITS applications. IEEE 802.11p is a branch of the IEEE 802.11 standard protocol, with well-known Wi-Fi protocols for wireless communication [38].

IEEE 802.11p communication modes include Dedicated Short-Range Communications (DSRC) and Cellular-V2X (C-V2X) [39,40]. DSRC is a peer-to-peer communication channel that allows cars and infrastructure to interact directly with one another, whereas C-V2X leverages a cellular network to offer wide-area coverage as well as extra services like multimedia streaming. Even in high-mobility environments, these techniques help minimize delays and increase the chances of successful transmission. There are many security mechanisms to prevent unwanted access and data manipulation. Features include message encryption, message authentication, and access restrictions based on digital certificates. The US, Europe, and Asia have all adopted DSRC to a large extent. In the US, the National Highway Traffic Safety Administration (NHTSA) has mandated DSRC in all new cars sold in the country starting in 2023 [38,40].

IEEE 1609 defines V2X communication requirements for ITS applications. IEEE 1609.1, which specifies the architecture and requirements for (WAVE); IEEE 1609.2, which defines security services and protocols and IEEE 1609.3, which defines networking services. IEEE 1609 is utilized in V2V and V2I communication in ITS systems, providing real-time traffic information exchange, collision avoidance, and emergency response [37,40]. The wireless communication standard IEEE 802.15.4 enables low power, low data rate communication between devices in the 2.4 GHz frequency range. This protocol enables environmental monitoring and traffic flow analysis in ITS systems for sensor networks. This protocol can also be used for V2I communication to exchange real-time traffic data and implement intelligent traffic management. The final protocol, IEEE 802.22, enables long-distance communication between devices and operates in the TV white space frequency range (54–862 MHz). For ITS applications in rural and isolated locations, when other communication networks might not be accessible, this protocol is employed. Applications including vehicle tracking, emergency response, and environmental monitoring employ IEEE 802.22 [38,40].

3.2. Cellular vehicle-to-everything (C-V2X)

C-V2X is a cellular protocol that enables the communication between vehicles and infrastructure over current cellular networks. The coverage area of C-V2X can extend beyond that of DSRC and operates in the licensed cellular spectrum. To increase traffic efficiency, improve road safety, and improve the driving experience, C-V2X includes not only vehicle-to-network communication (V2N) but also the vehicle to pedestrian by Proximity Communication on the 5 GHz band (PC5), which provides short-range direct communication. Additionally, (LTE/5 G) for facilitating network communication, infrastructure, and cloud. PC5 enables direct communication between vehicles and nearby infrastructure, while LTE/5 G enables communication over wider areas, including telecommunications over cellular networks [41]. Applications like traffic management, real-time navigation, and remote vehicle diagnostics can all be made possible via C-V2X [42].

C-V2X is more economical than DSRC since it benefits from the already existing cellular infrastructure. C-V2X also supports sophisticated applications like remote vehicle control and automated driving. In addition, it makes a wide range of communication services, such as safety, security, and transportation-related services possible. Avoiding collisions, alerting emergency vehicles, Blind spot detection, intersection collision warning, and forward collision warning are all a few examples of emergency safety services. Services connected to traffic efficiency include eco-driving, Signal Phase and Timing (SPaT), and real-time traffic information. Examples of infotainment services include streaming media in-car, online radio, and navigation. Briefly, C-V2X can handle both LTE and 5 G networks, allowing it to leverage current cellular infrastructure, support future 5 G networks, and be more scalable and economical, which makes it better than any other communication system, especially its competitor DSRC [38,42].

Fig. 4 shows the implementation of the C-V2X services on the Multi-Access Edge Computing (MEC) platform and the use of a wireless interface (PC5 or Uu) to provide pertinent information to road users. MEC equipment can be used at the roadside in challenging environmental situations. Some models with high AI processing demands are also appropriate for the cloud edge. They are connected to several cameras, radars, and lidars along the roadside. For computer vision-based video analytics of the objects, incidents, and status on the highways, they are often utilized to produce V2X Messages with very low latency. The PC5 air interface, also known as sidelink, is the medium through which the Roadside Unit (RSU) communicates V2X Messages and SPaT information to the other road users (automobiles and pedestrians) in the immediate vicinity.

Additionally, the Traffic Signal Controller (TSC) is stationed at the roadside to read the (SPaT) information in real time. In addition to this, it can be connected to the Access Network in order to provide this traffic data for processing to the Cloud-Edge MEC Platform, as well as other MEC platforms and systems within the Smart City, such as the Intelligent Traffic Management System (ITMS) [42]. Roadside sensing devices such as cameras and LiDARs, as well as the processing outputs of these devices (such as V2X Messages), are broadcast to surrounding vehicles and pedestrians through the RSU [43]. MEC at the intersection, the PC5 link is utilized to broadcast V2X messages and information regarding SPaT to various users of the road, including pedestrians and drivers of vehicles. The connection between vehicles and RSU [42,45] is shown in Fig. 5.

3.3. LoRaWAN: long range wide area network

LoRaWAN is a wireless communication technology that is becoming increasingly popular in ITS applications; known for its low-power and long-distance data transfer, making it suitable for applications that require communication over a wide area. This is particularly important for ITS applications where vehicles and infrastructure are spread over a large area [44].

LoRaWAN technology can be used in ITS for various applications such as traffic monitoring, V2V and V2I communication as traffic flow, vehicle speed, and other metrics in real-time; this information can be used to optimize traffic signal timing, re-routing, or provide real-time traffic updates to drivers [44]. One of the useful applications which saves too much time is smart parking applications; LoRaWAN sensors can be placed in individual parking spots to detect when a spot is occupied or not. This information can be transmitted to a central server, informing drivers of available parking spots in real time, reducing congestion and improving traffic flow. LoRaWAN can also handle many devices simultaneously, with each device having a unique identifier that ensures secure communication. LoRaWAN uses AES 128-bit encryption to safeguard device communication. However, it is also distinct in that it offers several benefits over competing wireless communication technologies, which makes it appropriate for ITS applications. For example, the low power consumption of LoRaWAN, which guarantees extended battery life for IoT devices, is one of its key advantages. Therefore, LoRaWAN is important for ITS applications since it lessens the frequency of battery maintenance and replacement [44].

3.4. 5G Technology

5 G enables the evolution of VANETs by enabling real-time solutions for intelligent traffic systems. Tracking vehicle and passenger movements in real time with the help of 5 G enables an improved reaction to delay and unforeseen situations such as emergency vehicles. Providing visual computing capabilities for AI cameras and sensors connected to buildings, on the road, and within cars. Fig. 6 briefly lists the advantages of a 5 G network in ITS [45,46].

For a variety of applications, 5 G technology is intended to offer high-speed, low-latency wireless communication. High-definition video and

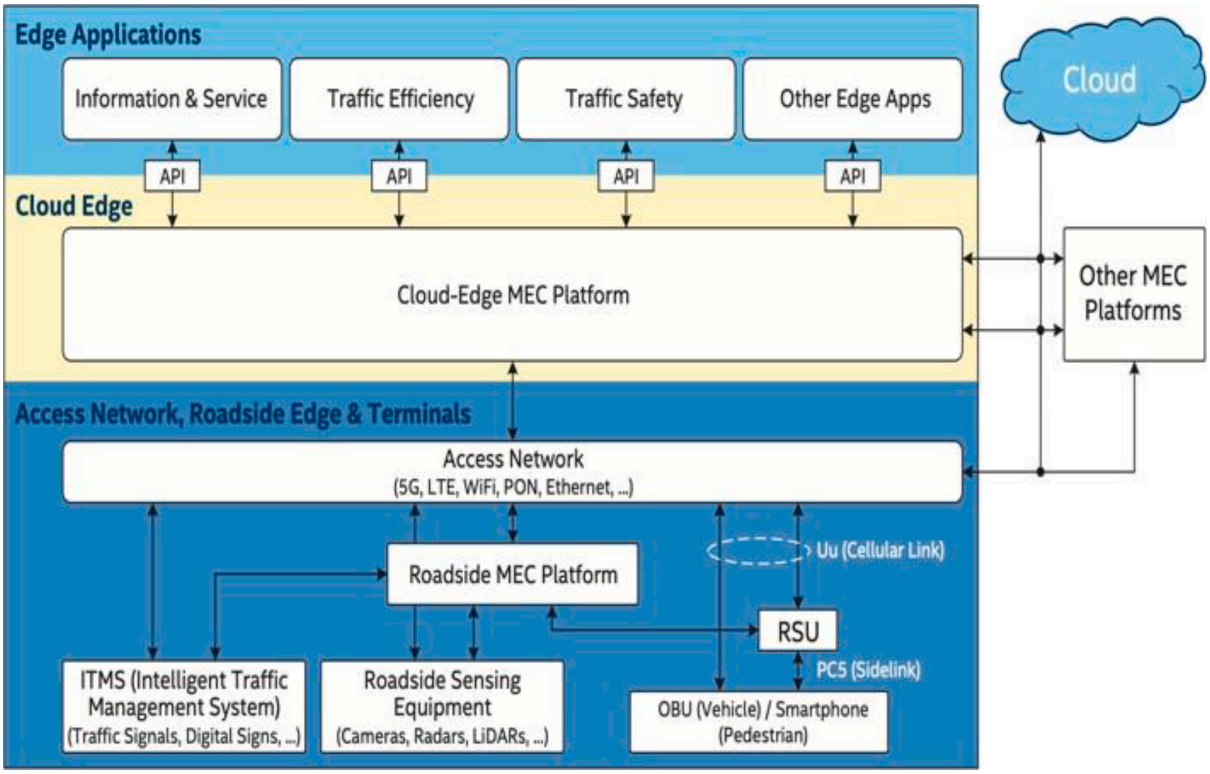

Fig. 4. Implementation of C-V2X services on MEC platforms [42].

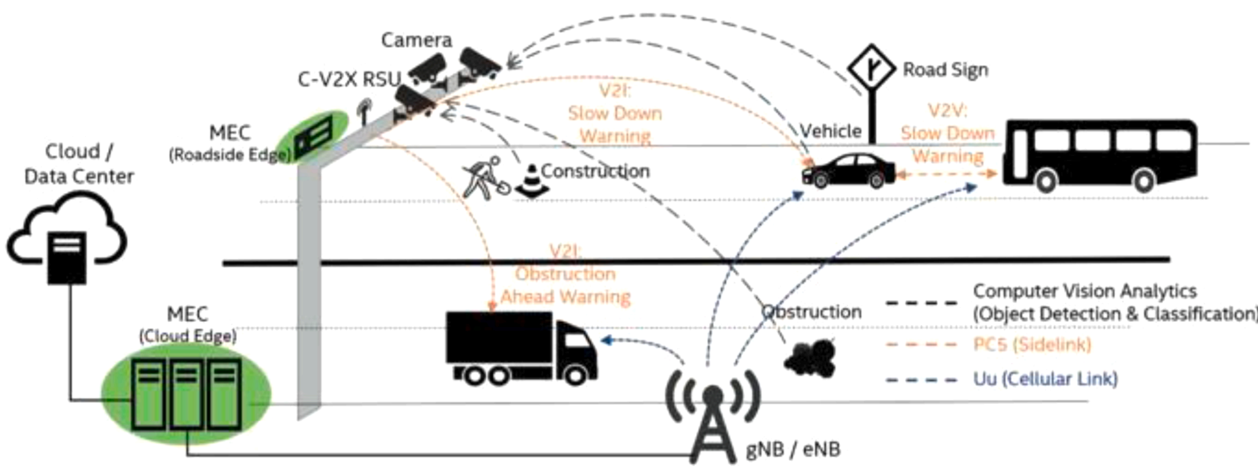

Fig. 5. Vehicle To Roadside Units (V2R) [42].

other rich information may be shared thanks to 5G's huge data transfer capacity and high bandwidth. 5 G can deliver fast connectivity in VANETs, allowing for the real- time sharing of data, including position, speed, direction, and monitoring. This may increase security, ease traffic, and make new services like platooning [45,46].

A platoon is like an automobile community in many ways. Nevertheless, it enhances the community's usefulness by adding a lead vehicle that gathers data on the road ahead and directs the traffic behind it. It can also be used to enable vehicles that can manage steering and braking but lack any self-driving algorithms or other instruments for keeping an eye on the road. It can have a self-driving algorithm but in a different way. For example, if two local transportation buses are going to the same location, the first one should be with a driver and receive the broadcast of road conditions and warnings and lead the bus behind it that doesn't have a driver, so by this way, we increased the bus capacity to be two buses going into the same location and reduce the burden on human users driving their automobiles, and thus the number of road collisions [45].

The development of a network system that can support multiple nodes connecting to the network without significantly slowing down the network connection is a primary priority. The network's ability to effectively handle broadcast messages is another crucial component. Since many VANET applications transmit safety or warning information to all nearby cars, networks must have an effective and quick broadcast handling mechanism [44]. By adding a new layer to the network design called "clusters," we can assist in limiting the amount of data packets generated by broadcast messages, which is one of their main issues. These clusters are a collection of vehicles that can communicate and are all close to one another as shown in Fig. 7 [45]. A single broadcast is sufficient to reach all of the cars in the cluster because they can

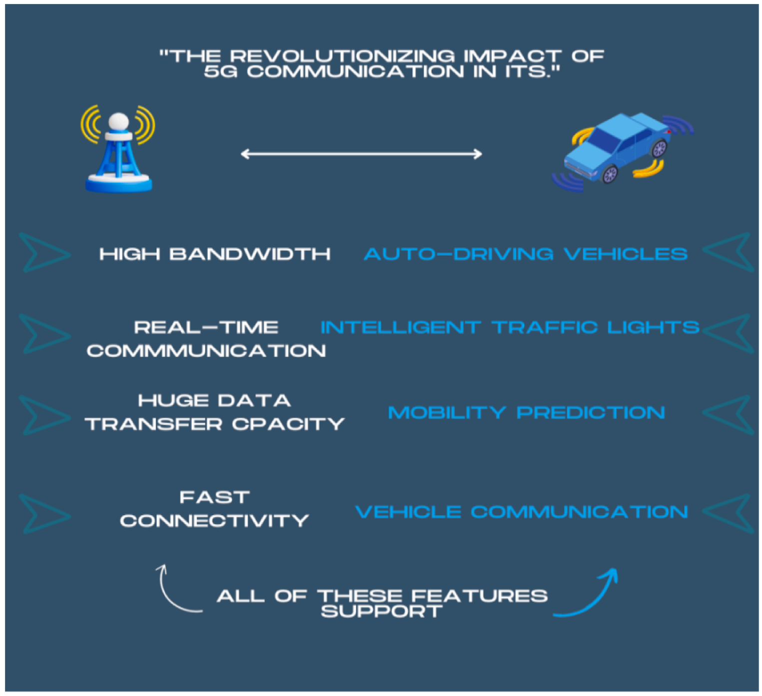

Fig. 6. 5 G advantages.

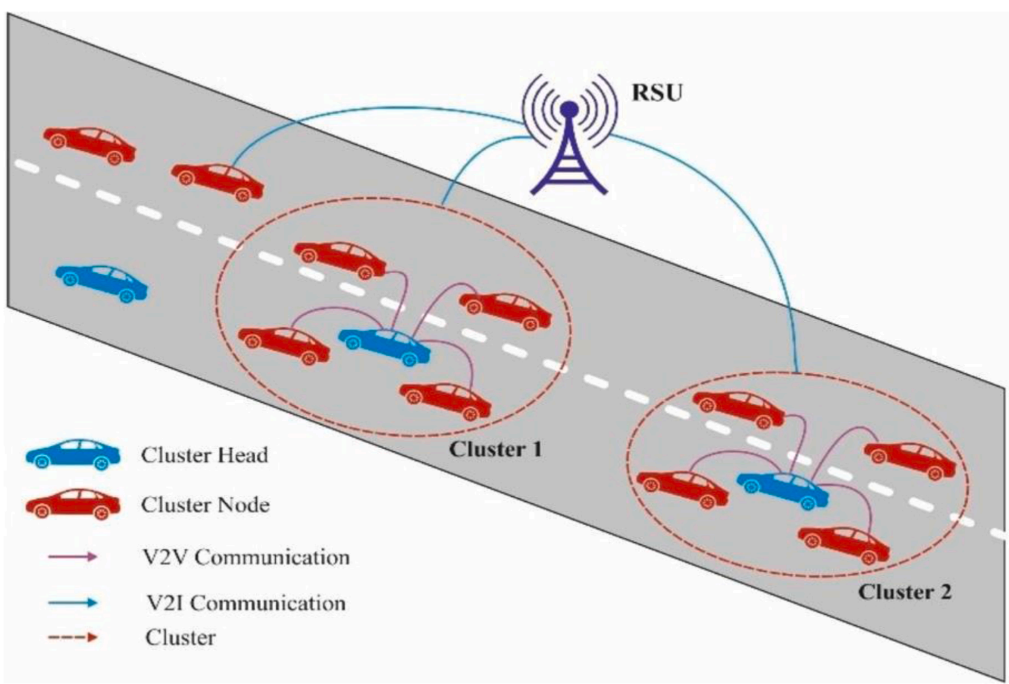

Fig. 7. Clusters division [61].

communicate with one another. Afterward, the cluster head would communicate with other cluster heads in the area to let them know what was in the broadcast message and ask them to spread it to their clusters. This reduces the number of packets that must be transferred over the network for a broadcast message to reach every vehicle in the network.

5 G can also support a large number of connected gadgets. This is essential for VANETs and RSUs, which must connect to tens of thousands of vehicles and roadside infrastructure devices. Low-band, mid- band, and high-band frequencies comprise the three frequency ranges that 5 G networks use to function. Mid-band frequencies have higher data transfer speeds, high-band frequencies have the fastest transfer speeds but lower coverage, and low-band frequencies have a wider coverage area.

RSUs transmit data at fast rates to nearby cars and equipment using the mid-band frequency. In order to facilitate smooth contact between cars, infrastructure, and other devices, they are typically placed along freeways and congested roadways [18]. Through receivers mounted on the RSU, data is transmitted and received during operation. The RSU can use Dedicated Short-Range Communication (DSRC) or Cellular- V2X (C-V2X) technology to interact with cars. While DSRC utilizes a designated communication channel for vehicle-to-vehicle and vehicle-to-infrastructure communication, C-V2X enables direct contact between vehicles and infrastructure [18,46].

Robust communication technologies are required to develop smart cities and intelligent transportation systems. They allow the smooth flow of information between various components of these systems, real-time data gathering and analysis, and the development of intelligent transportation systems that optimize traffic flow, decrease congestion, and improve safety. As urbanization grows, the value of these technologies will only expand, and their continuing development will be vital to maintaining the sustainable growth of cities.

4. Security challenges in ITS

According to research into ITS, VANET technology and IoT equipment are becoming more vulnerable to security breaches. Secured ITS against ever-changing Cyber Threats is crucial to guaranteeing the dependability and safety of transportation systems.

VANETs face substantial difficulties due to attacks on authenticity, such as Sybil attacks. The goal of a Sybil assault is to manipulate trust and even impair the network's operation by tricking genuine nodes into believing a series of falsehoods. Attackers can generate false information on traffic conditions or road dangers by taking advantage of the dispersed nature of VANETs, which can cause traffic jams or accidents. Current methods frequently fail to distinguish between real and false identities, making it difficult to detect Sybil assaults owing to technological constraints. To successfully detect and stop rogue nodes, strong authentication measures and regular monitoring are necessary for Sybil attack mitigation [47].

Wireless communication technologies are becoming increasingly common in ITS, which opens the door to new security risks. Flexible and broad communication between ITS components is enabled by technologies like DSRC/WAVE, Cellular-V2X, Bluetooth, and GNSS. However, these same technologies also allow attackers ways to get remote access. An attacker might remotely compromise the whole vehicular network by exploiting weaknesses in various wireless technologies. For example, telematics devices' Internet services or built-in cellular capabilities are vulnerable to long-range assaults. Wireless technologies with limited ranges, such as Bluetooth and Wi-Fi, can be exploited to target neighboring vehicles or roadside equipment; hence, strong security measures are necessary to prevent unwanted access [47].

In addition, ITS security has major threats from software flaws in linked vehicle systems. Due to the heavy reliance on software in modern automobiles, they are susceptible to cyber attacks due to vulnerabilities such as injection holes and buffer overflows. Vulnerabilities in automotive systems can be used by attackers to introduce malicious code, which can then manipulate or access essential components without authorization. Identifying and efficiently patching vulnerabilities is made more complicated by the complexity of the software in connected cars, which can contain millions of lines of code. Further complicating security efforts are the automobile industry's lightning-fast software development and integration cycles, which need constant vigilance and preventative security measures to deal with new risks as they arise [47].

Estimating Software Security using the Hybrid Fuzzy ANP-TOPSIS Method. Safety must be a top priority because of the interdependence of all the parts of an ITS system. Assessing and improving the security of software components inside ITS is possible with the help of the software security estimation technique described in this topic. Many other types of software systems are included in ITS, such as communication protocols, traffic management algorithms, and systems for controlling vehicles. Protecting the overall transportation system from cyber attacks requires evaluating the security of these software components. By taking into account elements like vulnerability assessments, attack surfaces, and possible security breaches inside ITS software, the hybrid fuzzy ANP-TOPSIS technique provides a systematic way to analyze software security. Ensuring the resilience of ITS infrastructure and decreasing the danger of cyber attacks are both achieved through this holistic strategy, which allows stakeholders to efficiently identify and prioritize security solutions [48].

When thinking about the possible effects on public safety, reliability prediction becomes even more important in ITS to guarantee transportation networks' consistent and reliable operation.

From an industrial standpoint, dependable forecasts are necessary for stakeholders engaged in creating and implementing ITS systems to foresee and reduce the impact of possible system faults or interruptions. Industrial practitioners can prioritize efforts to improve transportation efficiency and safety by understanding the reliability needs and challenges specific to ITS. This knowledge allows them to optimize maintenance schedules, allocate resources efficiently, and minimize downtime. Manufacturers and service providers can also benefit from accurate reliability forecasts for ITS components and subsystems. Decisions may be made with more certainty at every stage of an ITS infrastructure's lifespan, from planning and development to operation and maintenance, thanks to accurate forecasts [49].

From a reliability perspective, predicting software bugs in new and large datasets using a unified neuro-fuzzy approach: System failures, safety risks, and interruptions in traffic control are all possible outcomes of software errors, which can have devastating effects on ITS. Thus, it is essential to accurately foresee software faults to guarantee the performance and reliability of ITS applications. This subject presents a new way to anticipate software vulnerabilities using a unified neuro-fuzzy methodology, with an emphasis on dependability. A combination of neural networks and fuzzy logic allows this method to successfully deal with the complexity and uncertainty of ITS software. It takes the best parts of both methods and uses them together to provide better bug predictions so ITS engineers can find and fix problems before they get worse [50].

Developers and operators of ITS can improve system dependability and reduce the likelihood of accidents and service outages on highways by accurately predicting software flaws and fixing them before they become major problems. In addition, ITS firms may take a proactive stance towards software quality assurance by including bug prediction in the software development lifecycle. This will result in increased dependability and customer satisfaction [50]. These subjects show the continuous endeavors to guarantee the security, efficiency, and dependability of ITS by addressing crucial parts of software security, reliability prediction, and bug prediction inside this framework.

From a sustainability and energy efficiency perspective, ITS prioritizes sustainability and infrastructure that incorporates renewable energy sources and energy-efficient technology that helps reduce carbon emissions, improve environmental effects, and promote sustainable behaviors.

The indicated topic's decision-making framework might provide useful information for assessing the environmental impact of energy-related choices in ITS projects. Stakeholders may make better decisions to make ITS infrastructure and operations more sustainable by considering energy use, renewable energy adoption, and environmental effects. The Importance of Energy Efficiency in ITS, intelligent sensors, car charging stations, and traffic signals all rely on energy efficiency to function at their best and last as long as possible. Minimizing resource consumption, reducing operational expenses, and extending equipment lifespan are all possible outcomes of ITS systems' focus on energy efficiency [51].

The topic's hesitant fuzzy decision-making might be modified to assess energy efficiency measures in ITS projects. The framework may aid decision-makers in prioritizing energy-efficient solutions and technologies by combining hesitant fuzzy logic, which models uncertainties and preferences. This ensures that the most important environmental and economic advantages are achieved. ITS integrating renewable energy sources, sustainable energy solutions for transportation systems may be provided by ITS infrastructure that integrates renewable energy sources like solar and wind power. Intelligent traffic control systems, charging stations for electric vehicles, and roadside equipment may all be powered by renewable energy sources [51].

5. The impact of ITS implementation on the environment and sustainability

Currently, governments all over the world are facing a variety of challenges, including excessive energy use, air pollution, traffic congestion, high accident rates, unsatisfactory driving experiences, increasing idling time for drivers, and increased fuel consumption [52]. As a result of people moving from rural regions to urban areas in search of better work prospects and improved living circumstances, cities all over the world are seeing a significant increase in their population. Because of this, there will be a substantial amount of congestion in the traffic. The transformation of the city into a Sustainable Smart City is the ideal solution to the many issues that have been brought up. Implementing technologies such as ITS, Smart Buildings, and Smart Manufacturing is necessary to make every city smart and environmentally friendly. When it comes to the establishment of a Sustainable Smart City, the Transportation Industry is the first area that will be focused on, intending to transform it into an Intelligent Transportation System. Not only does this transition improve safety and cut down on fuel consumption, traffic congestion, and accidents, but it also makes a substantial contribution to sustainability by reducing the amount of energy consumed and the emissions of greenhouse gases [52–54].

The implementation of ITS is crucial for improving traffic flow, reducing emissions of harmful gases, lowering air pollution, reducing idling time for drivers, enhancing driving experience which contribute to the promotion of sustainability. Through the use of ITS technologies and 5 G real time network cities all over the world have demonstrated significant improvements in their Sustainable Smart City plans performance.

The deployment of ITS, facilitated by real-time communication technologies, notably contributes to the reduction of CO2 emissions from vehicles, thereby advancing cities towards eco-friendliness. For instance, ITLs represent an effective solution to reduce the CO2 from vehicles by optimizing traffic flow, reducing idling time, and reducing the number of stops and start vehicles make at intersections. ITLs use advanced sensors and machine learning to adjust traffic signals in real-time based on traffic flow, congestion, and other things [11]. The ITL system collects data about traffic behavior, vehicle speed, and the distance needed for the approaching vehicle to the traffic light using RSUs as sensors and cameras installed on the roads to predict light timings to suit the behavior of the street to minimize the idling time of the vehicles waiting for the traffic light to turn green and the number of times pressing accelerator and brakes while reaching at the intersection to reduce the CO2 emission and improve fuel efficiency [19,55–57].

Smart Parking is another technology that helps reduce CO2 emissions; it uses RSU and communication technologies to provide drivers with available parking slots in real-time through mobile apps. Smart Parking relies on implementing sensors or cameras in the parking spaces to detect the presence and movement of cars. These sensors are connected to the RSU, giving them real-time data about the available slots. The RSU sends the vehicles information about the available parking slots for the nearest parking area they are searching for. Accordingly, the vehicles will not need to keep moving around the parking area or wait for a car to leave to take its place for a long time. It can directly go to the available slots without consuming too much fuel and producing extra CO2 emissions.

ITS helps realize sustainable cities as it reduces energy wastes, pollutant emissions and improves the safety and livability of these cities. In addition to global warming, CO2 and other emissions such as Hydrocarbons (HC), Carbon monoxide (CO), Particulate matter (PM), Nitrogen oxide (NOX), Sulfur dioxide (SO2), PM2.5 and PM10 can cause serious health problems. PM2.5 and PM10 for instance, can affect children’s lung size and lung growth in the long run as they grow up [58–60].

Sustainability is all about fulfilling the current needs without affecting the ability of the upcoming generations to fulfill their own needs. By combining ITS technologies and 5 G communication, smart cities can acquire an eco-friendly transportation system. Vehicular Ad-hoc Networks (VANETs), Intelligent Traffic Lights, and Virtual Traffic Lights utilize real-time communication technologies to enhance traffic flow and minimize congestion leading to decreased fuel consumption and emissions. By doing this, we can lessen the harmful effects of transportation on the environment, which is good for sustainability.

Moreover, the utilization of 5 G real-time communication within smart cities can improve the effectiveness of ITS technologies. This allows quicker and more precise data gathering, evaluation, and decision-making. Reduced energy consumption and emissions and improved safety are crucial factors of sustainable cities and transportation systems [11].

A number of municipalities have initiated investments in ITS and environmentally friendly transportation techniques. Subsequently, these municipalities have cooperated with a variety of industries to develop Sustainable Smart Cities, which has resulted in a significant positive impact. Section 5.1 discusses case studies highlighting specific cities’ endeavors in transitioning towards Sustainable Smart CitiesThese cities include Los Angeles (USA), Montreal (Canada), Singapore (Singapore), Barcelona (Spain), Copenhagen (Denmark), Seoul (South Korea), Dubai (UAE), and New Administrative Capital (Egypt).

5.1. ITS impact on sustainable smart cities

For the purpose of predicting traffic trends and improving traffic control strategies, the city of Los Angeles has used mobility prediction algorithms. As a consequence of this initiative, there has been a reduction in the amount of time spent traveling, as well as a drop in the emissions of greenhouse gases. It is of the utmost importance to contribute to a more sustainable transportation environment since transportation is a significant contributor to greenhouse gas (GHG) emissions, with the sector accounting for 29 % of the overall emissions in the United States. The fraction of greenhouse gas emissions reached its highest point in 2021. Between the years 1990 and 2021, the transportation industry is responsible for the greatest increase in absolute terms in terms of greenhouse gas emissions of any other sector [62]. In 2023, the city of Los Angeles implemented an Intelligent Traffic Light (ITL), which resulted in a reduction of travel time by 16% and a reduction of pauses at intersections by 12 % [63].

In the year 2019, a case study was carried out on the city of Montreal, which is located in Canada and is a highly populated metropolitan area with around 4 million citizens. The city of Montreal has significant challenges in the areas of pollution, excessive traffic, and safety. To cut down on the amount of fuel used and the amount of carbon dioxide emissions, the city was converted into a Sustainable Smart City [64].

In terms of traffic light management, Montreal is rapidly becoming an intelligent city; in fact, about half of the city’s traffic lights are now considered "intelligent." All of these lights are linked to a master network by a group of experts using fiber optics or wireless communication technology. The traffic lights may be adjusted in real-time according to current occurrences thanks to this configuration. When an accident happens at a crossroads, for example, operators can quickly shut off the area to allow for faster aid arrival without traffic delays.In order to improve emergency response, the Montreal ITS strives to detect issues proactively. When it comes to incident detection, thermal cameras mounted on bridges are crucial. These cameras can detect vehicle signatures and even distinguish between different types of vehicles. The technology notifies the monitoring agents when a vehicle stays still for a long time, allowing them to respond quickly. In addition, the ITS has AID software that uses the already-installed camera infrastructure to spot moving objects, accidents, or noises [64].

Emergency calls and car location alerts are two examples of the many forms that motorist support services might take as part of Montreal's ITS emergency management system. These services rely heavily on sensors that are built into automobiles. These sensors assess the level of damage in the case of an accident or impact and decide whether to call an operator or emergency services directly. In general, the integration of ITS in Montreal shows a thorough strategy to improve the city's emergency response capabilities and traffic management [64].Approximately sixty percent of the incidents that occurred on highways might have been averted if drivers had been provided with warning signs just a few seconds before the hit, according to the findings of the research [65–67].

To enhance its transportation system, Singapore makes use of sophisticated sensors and data analytics. This allows the country to better regulate the flow of traffic and therefore reduce congestion. As a part of its commitment to sustainability and transportation, Singapore has established a goal to lower the intensity of its carbon emissions by 36 percent by the year 2030 and to remove all emissions from public transportation [68]. A great number of Internet of Things sensors have been deployed throughout the city to collect data in real-time on a variety of parameters, including the flow of traffic and the amount of energy that consumers consume. In addition to cellular networks that enable 5 G technology, these sensors are backed by a high-speed fiber optic network. An intelligent transportation system (ITS) that makes use of data collected in real-time has been established in Singapore [69].

The advanced traffic management system in Barcelona makes use of real-time data to monitor traffic flow and make adjustments to traffic lights in order to improve traffic flow and alleviate congestion. Monitoring mobility patterns and enhancing the effectiveness of the city's transportation system have been accomplished by Barcelona through the utilization of a wide variety of data collecting and analysis techniques. Real-time information on the current traffic conditions is provided to drivers by the city through the implementation of a traffic data platform that collects data from traffic sensors and provides this information to drivers. Several initiatives have been implemented in Barcelona to lower emissions and enhance air quality. This strategy calls for the establishment of low-emission zones as well as the promotion of the usage of electric vehicles [70].

Intelligent parking systems have been established across the city of Barcelona. For the purpose of directing vehicles to the next vacant parking place, the gadgets make use of sensors to identify vacant parking spots. Because of this strategy, the amount of time spent looking for parking has decreased, which has led to a reduction in both traffic congestion and pollution. Using data collected in real-time, the automated traffic management system in Barcelona can monitor the flow of traffic and make adjustments to the traffic lights. This identifies it as an ITL system that operates based on real-time data, in contrast to traditional systems, which operate based on predefined periods and do not take into account the circumstances of the road [70].

Copenhagen is working toward the goal of being carbon neutral by the year 2025. In order to accomplish this goal, the city is introducing measures such as sustainable transportation and smart street lighting to encourage its residents to adopt a more environmentally friendly way of life [68]. To lessen the amount of congestion and enhance the flow of traffic, the city has implemented several novel approaches to traffic management. The sophisticated traffic management system of the city makes use of real-time data to monitor the flow of traffic and make adjustments to the placement of traffic lights in order to improve the flow of traffic and alleviate congestion. An intelligent parking system has been implemented by the city. This system makes use of sensors to identify unoccupied parking spots and then guides vehicles to the next available place. Because of this, the amount of time spent looking for parking is reduced, and congestion is reduced as well.

Furthermore, in addition to the measures mentioned above, Copenhagen has implemented a multitude of intelligent mobility technologies to enhance accessibility and safety. Many pedestrian and bicycle detection systems have been installed at key intersections throughout the city to reduce the likelihood of accidents occurring. The presence of pedestrians and bicycles is brought to the attention of motorists by these devices, which increases safety. Additionally, the city has implemented some accessibility efforts, such as low-floor buses and tactile pavement for people who are visually impaired [70].

The city of Copenhagen has developed transportation solutions that are intelligent and focused on supporting environmentally friendly modes of transportation systems. The city of Copenhagen has established itself as a frontrunner in the fight against climate change and the reduction of greenhouse gas emissions on a worldwide scale as a result of its commitment to environmentally friendly modes of transportation, which has improved the quality of life of its residents [70].

The Seoul Metropolitan Government aims to become a leading smart city by consistently utilizing big data and cutting-edge information and communication technologies. Many have called big data "the new oil of the 21st century," and it is already finding its way into Seoul's approaches to city planning. Seoul has been striving to become the premier e-government metropolis for the past twenty years, and it has succeeded. To promote economic growth and the creation of new services, the municipality plans to utilize blockchain and IoT, two significant technologies connected with the fourth industrial revolution.

In order to accomplish this goal, Seoul plans to install 50,000 Internet of Things sensors all throughout the city to gather information on a variety of urban phenomena. In addition to the levels of noise and motor traffic, the phenomena will also include the amounts of particulate matter. To improve urban management and provide direction for policymaking, these data will be examined and provided input. VANETs, Smart Parking, and Artificial Intelligence Taxis are some of the creative ideas that Seoul will use in the transportation business in order to handle the issues that come with metropolitan life. Through the ability to anticipate demand and take into account a wide range of criteria, the AI Taxis will improve taxi services.

Through the implementation of cutting-edge surveillance cameras that make use of big data and artificial intelligence technologies, the city intends to improve the level of local security. The use of these cameras will make it possible to respond to accidents more quickly since they will analyze video clips and automatically recognize potential threats to safety and road conditions. The administrative services, transportation, security, environment, welfare, and economics sectors are the six primary areas that are included in the smart city program that Seoul has implemented [71]. The implementation of these technologies and concepts will improve urban living and provide solutions to global concerns, which will ultimately result in an improvement in the quality of life for people and position Seoul as a center for the development of smart cities. Through the implementation of the Smart City Seoul Plan, the administration of the Seoul Metropolitan Area is dedicated to achieving the goal of making Seoul the smart city with the highest level of technical advancement in the world [71].

The employment of cutting-edge technology and the city's highly developed infrastructure have earned Dubai a well-deserved accolade. A high-speed rail system and a smart traffic management system are two examples of new modes of transportation that the city has built in order to improve mobility. In order to back its smart city ambitions, Dubai has poured a lot of money into modern infrastructure projects. The creation of 5 G networks, the deployment of Internet of Things technologies, and high-speed fiber optic networks are all necessary for this goal. The city has developed a smart parking system that uses sensors and smartphone apps to help drivers find vacant parking spots at specific times. [69,72].

Through the execution of a number of different environmental programs, the United Arab Emirates is making significant efforts to realize its goal of reaching net-zero emissions by the year 2050. It is the goal of the National Climate Change Plan 2017–2050 of the United Arab Emirates to reduce emissions of greenhouse gases by 70 % by the year 2050. In order to accomplish this objective, the United Arab Emirates (UAE) has launched a number of sustainability projects, including the UAE Energy Strategy 2050 and the Dubai Clean Energy Strategy 2050, amongst others. By the year 2050, it is anticipated that the energy mix of the United Arab Emirates would contain renewable energy sources at a rate of 50 %. This will be accomplished through the execution of the Energy Strategy. By the year indicated, the Clean Energy Strategy aspires to create Dubai as a major hub for clean energy and a sustainable economy. This will be accomplished by meeting 75 % of the city's energy consumption from clean sources. It is via the achievement of a lofty goal that this will be done. To achieve the objective of reaching 25 % autonomous mobility in Dubai by the year 2030, the United Arab Emirates (UAE) has established many sustainability projects linked to transportation. All of these plans include the Dubai Autonomous Transportation Strategy, which is one of them. The objective of this initiative is to accomplish the reduction of pollution and congestion in the transportation sector while simultaneously enhancing safety and efficiency. As a result of the implementation of sustainability programs and projects, rural regions have experienced a reduction in emissions, an increase in the conservation of resources, and an improvement in the quality of life [73–72].

All of the cities above are working hard to improve the quality of life in their communities by emphasizing issues such as air quality, energy efficiency, fuel usage, and environmental sustainability. ITS has the potential to have a significant impact on the overall sustainability of smart cities. A number of neighborhoods in Egypt, notably the New Administrative Capital, are now undergoing the process of being transformed into smart cities. With the help of this effort, the high population density and traffic congestion in Cairo will be alleviated. This will be accomplished by encouraging people to migrate to a living environment that is more environmentally friendly and technologically sophisticated. In order to monitor road conditions, control traffic, and provide real-time updates for all modes of transportation, including smart parking technology, the city intends to implement ITS, which will make use of intelligent sensors, artificial intelligence cameras, real-time cellular networks, and smart ticketing technology [69,75].

In 2016, 123,000 people sustained serious injuries and 25,000 people passed away as a result of vehicle accidents across Europe. Non-motorized road users, mostly pedestrians and bicycles, were responsible for around 29 % of the deaths that occurred across the country [76].

After the 31st of March 2019, all new automobile models sold in Europe will be required to be supplied with an Automatic Emergency Call System and receive approval from the European Union. The implementation of a system that will allow drivers to swiftly contact emergency services either through a voice call or through sensors present in the vehicle that will automatically identify accidents and make emergency calls in order to shorten the amount of time it takes for emergency services to respond and to improve safety. In order to offer full information on the precise position of the car that was involved in the collision, as well as details regarding the vehicle and the state of the accident, the location of the accident is accurately relayed. This took place through the utilization of VANETs, in which the call is made through the utilization of a vehicle communication system that is completely integrated with the automobile and is connected to a cellular network [77]. A 5 G cellular network, which provides high priority, low latency, real-time data transfer, and is immune to network congestion, contributes to the effectiveness of the emergency response system by making it more efficient. In order to improve the intelligence and usefulness of the system, a vehicle that is engaged in an accident can send a warning message to other vehicles that are nearby or vehicles that are approaching the accident spot. This message will advise the other vehicles to slow down and remain attentive in order to prevent a collision. In addition, after the car has transmitted its location to the emergency services, a drone may be sent to the area to offer live streaming of the event. This gives the authorities the ability to precisely analyze the situation and provide the required aid. Currently, emergency services have access to more detailed information on the situation, which enables them to work with enhanced speed and efficiency within their operations. It is recommended that all streaming and warning messages be provided using real-time communication made possible by 5 G to enhance the system with instantaneous updates.

This method is utilized not just in autos manufactured in Europe but also in motor vehicles manufactured in a variety of other countries throughout the world, such as China, Saudi Arabia, the United Arab Emirates, and Russia [78]. When it comes to intelligent transportation systems in smart cities, the automobile needs to be outfitted with cutting-edge technology in order to be properly connected. This technology should improve driver safety by providing emergency services with accurate information about accidents, including the actual position of the vehicle involved, to ensure prompt and effective assistance. The majority of investments in the transportation sector in the United States, Japan, and Europe are focused on vehicle-to-event networks (VANETs), followed by other intelligent transportation systems (ITS) technologies to improve driving safety and reduce traffic congestion. The majority of China's spending is directed at RSU technology, which includes artificial intelligence cameras and sensors for video surveillance systems. These systems include facial recognition and license plate identification capability [79]. Depending on the various technological deployment scenarios and discount rates, it is anticipated that the total annual expenditures for the year 2020 will range anywhere from $0.3 billion to $2.1 billion. The expenses reached their highest point between 2022 and 2024, which was between $1.1 and $6.4 billion, and then steadily decreased to a range of $1.1 to $4.6 billion [80]. The United States of America and China are the two most important markets for smart city technology. These two countries are seeing annual growth rates of 19 % and 19.3 %, respectively, and have a total market value of $22 billion and $10 billion, respectively [79].

Due to the fact that automobile collisions are the leading cause of death on a global scale, it is of the utmost importance to implement information technology in each and every city throughout the globe in order to successfully reduce the number of accidents. It has been estimated by the World Health Organization (WHO) that more than thirty million individuals all over the world have lost their lives as a result of vehicle accidents since the invention of the automobile. There have been between 150,000 to 160,000 traffic accidents in China that have resulted in injuries, with over 40000 fatalities, according to numbers that have been taken from yearbooks collected over the past few years. Over 90 percent of all people who were involved in automobile accidents did not make it to the hospital alive. On the other hand, injured individuals who were successfully transported to hospitals had a heightened likelihood of surviving their injuries. Despite a high 98 % rate of timely rescues within 30 min, Japan has a low traffic mortality rate of 0.9 %. This underscores the necessity of implementing mandatory eCall laws [78].

The Texas A&M Transportation Institute conducted a poll that was released in 2019 and found that the discomfort caused by traffic congestion in the United States resulted in about $190 billion in wasted fuel and lost time expenditures. This information was derived from responses to the survey. In addition to this, it led to an additional 36 million tons of emissions of greenhouse gases that were not necessary to be produced. The Federal Highway Administration (FHWA) has issued forecasts that indicate that by the year 2049, the total number of miles driven by vehicles is anticipated to have increased by a factor of 22 percent.It is possible that this prognosis would lead to increased traffic congestion and related difficulties on highways in the United States [81–83].

There was a considerable reduction in the number of collisions that occurred as a result of the implementation of ITS, according to research that was carried out by the Government Accountability Office (GAO) of the United States of America. Specifically, between the years 2011 and 2018, there was a decrease of around five percent which was seen on some routes. Additionally, the utilization of VANETs has the potential to improve the environmental sustainability of the surroundings. The results of simulations indicate that complete connection among vehicles on the road might potentially result in a reduction of 8 % in both the average amount of time spent traveling and the amount of energy consumed. There is the potential for environmental benefits to arise from the partial introduction of connected cars [83]. Table 1 below summarize the achievements the mentioned cities have gained when implementing ITS.

Table 1
How specific cities got benefit from implementing ITS.

City	ITS Technology	Achievements	References
I. Los Angeles, USA	• ITL • Traffic prediction • Mobility prediction	• Reduction of travel time by 16% and pauses at intersections by 12 % • Reduction in GHG emission	[62,63]
II. Montreal, Canada	• VANETs (V2P & V2I) • ITL • Cameras	• V2P could decrease the accidents rate by 60 %. • Reduction in fuel Consumption and CO_2 emission. • Fast emergency services	[64]
III. Singapore, Singapore	• Traffic monitoring by real time data from sensors and cameras with the help of 5G	• Regulate traffic flow. • Reduce congestion. • Established a goal of 36 % Carbon emission.	[68,69]
IV. Barcelona, Spain	• ITL • Smart Parking • Real time automated traffic management	• Reduction in traffic congestion • Reduction in air pollution • Less idling time	[70]
V. Copenhagen, Denmark	• Smart parking • Traffic monitoring by real time data • ITL • VANETs (V2P)	• Being carbon neutral by the year 2025 • Regulate traffic flow. • Reduce congestion	[68,70]
VI. Seoul, South Korea	• IoT Sensors • VANETs • Smart Parking • AI Cameras • Traffic Monitoring	• steady progress toward its goal of becoming a leading smart city. • Improve in local security. • Respond quickly to accidents. • Improvements in the quality of life	[71]
VII. Dubai, UAE	• Smart traffic management system. • Development of IoT & 5 G networks • Smart Parking	• Reaching net-zero emissions by the year 2050. • Reaching 25 % autonomous mobility by the year 2030. • Established many sustainability transportation projects. • Reduction in traffic congestion • Reduction in air pollution • Enhancing safety and transportation efficiency • Improvement in the quality of life	[69,72, 73.74,72].
VIII. New Administrative Capital, Egypt	• Traffic Monitoring by real time data • Smart Parking • Intelligent Sensors • AI cameras • real-time cellular networks	• undergoing the process of being transformed into smart city • Eco-friendly environment and technologically sophisticated	[69,75]

5.2. Automotive manufacturers adoption of ITS technologies

In order to enable their cars to take part in ITS for smart cities, a number of automobile manufacturers are incorporating cutting-edge technology into their automobiles. They are using the technology of VANETS to stay up with the tremendous improvements that are occurring in transportation systems all around the world. When it comes to giving real-time information on traffic congestion, alerts, and warning messages, the technology of VANETs is very necessary. This helps to improve the whole driving experience and makes driving safer. Several automobile manufacturers, including Mercedes-Benz, BMW, Audi, Cadillac, Volvo, and General Motors (GM), have contributed significantly to the advancement of this field.

Since 1980, BMW has been integrating on-board computers for Formula 1 vehicles, which has allowed the company to acquire a significant amount of competence in VANETs. The year 2004 marked the beginning of BMW's implementation of SIM cards by the company. These cards made it possible for drivers to make use of internet services such as texting, maintaining office operations, and receiving weather reports. In addition to this, they enable motor vehicles to evaluate the level of traffic congestion by employing anonymous tracking [84].

The development of BMW's commitment to the utilization of connected vehicle technologies includes the incorporation of automobiles into municipal infrastructures that are smart. Since the year 2010, BMW automobiles have been equipped with the potential to communicate with their surroundings, including other automobiles, the cloud, and pedestrians, in order to share information. The process of connecting automobiles through networking has several benefits and prospects, including the enhancement of traffic flow, the resolution of issues that arise in big cities, and the promotion of environmental and safety objectives [84].

From 1998 till 2018, BMW has been at the forefront of connected automobile technology. The company began with the introduction of BMW Assist, which is now known as BMW ConnectedDrive and will be available in 45 countries. A wide variety of digital services are made available to more than four million customers through the BMW ConnectedDrive program. When it comes to incorporating the linked automotive into the routines of drivers, these services are very necessary. The development of technology has resulted in the introduction of innovations such as the BMW Intelligent Personal Assistant [84].

The future that BMW sees is one in which automobiles are completely interwoven into our digital lives, with seamless connections between various gadgets and services around the world. The development of autonomous vehicles is strongly dependent on connected automotive technologies, which are rapidly becoming an industry standard due to their widespread use. The future that BMW envisions is one in which autonomous driving and smart cities will revolutionize the driving experience by lowering levels of stress and increasing levels of resource efficiency [84].

Within its automobiles, BMW has successfully implemented the technology known as VANET, which enables them to establish connections with both the infrastructure of traffic and with other cars. This interface makes it possible to get real-time traffic updates, hazard alerts, and other information relevant to safety, which improves mobility in terms of both safety and efficiency [84].

In addition to BMW, a number of other automotive manufacturers have started using VANET technology in their vehicles. Automobile manufacturers such as Audi, Mercedes-Benz, Volvo, Ford, General Motors, and Cadillac are among those involved. The widespread use of this technology contributes to the development of intelligent transportation networks across the world, which in turn provides cities with transportation options that are cheaper, safer, and better for the environment [84].

Mercedes-Benz link also involves automobiles communicating with each other and with infrastructure. This marks the beginning of a new age of VANETs, notably V2X technology. This innovation makes it possible for vehicles that are connected to one another to share real-time data, foresee potential threats, and avoid crashes. As a result, it enhances both safety and convenience, and it represents a significant step forward in the development of autonomous driving technology [85].

The V2X technology enables cars to connect autonomously via mobile radio or WiFi. Car-to-car communication is already being utilized by the E-Class and S-Class models to notify other drivers of potential dangers like as accidents or road conditions that may be hazardous. Moreover, these automobiles are equipped with the capacity to establish a link between themselves and the infrastructure. This allows them to send vital information to a central server, such as information on blocked crossings or limited visibility. This transforms the automobile into an essential component of IoT [85].

During road construction, the state of Hesse in Germany is taking the initiative to build a comprehensive warning system to safeguard both vehicles and the individuals responsible for road maintenance. This system is extending the network as infrastructure provides information. Vehicles will be able to communicate with traffic signals in the future, which will result in improvements to both the flow of traffic and the safety of drivers. The "Sichere Intelligente Mobilität - Testfeld Deutschland" program emphasizes the importance of safety by proving the enormous safety benefits associated with V2X features. The use of these functionalities can reduce the annual economic expenses that are incurred as a result of accidents by billions of euros [85].

Vehicles manufactured by Mercedes-Benz already come equipped with sophisticated safety features such as Collision Prevention Assist and Distronic Plus. V2X technology improves the capabilities of the "Intelligent Drive" system that is currently in place. The vehicles will be able to get information about forthcoming impediments, alternative routes will be suggested, and user-friendly parking features such as "Community-based Parking" will be made available in the future. Additional services offered by the Parking Pilot include automatic smart parking through the use of smartphone applications. These services ensure increased comfort and safety in parking facilities that are intelligent and completely linked [85].

In 2024, Audi started providing 5 G connection as an option for its automobiles. Improvements in V2X communication that will lead to safer vehicles and a more satisfying driving experience. As early as the 2015 Audi A3, the business was ahead of the curve when it came to standardizing Wi-Fi and 4 G LTE connectivity in automobiles. When 5 G connectivity is introduced to American automobiles, they will lead the pack in terms of innovation. [86]

Accurate real-time traffic and congestion updates are collected by Audi's V2X, which can simply link to a city's traffic infrastructure and gather data. It is believed that road safety will be enhanced with the addition of V2P communication to Audi cars, which will decrease the probability of pedestrian traffic accidents. [86]

On a similar development, GM has joined forces to ensure that all Buick, Cadillac, GMC, and Chevrolet automobiles will have 5 G networks installed by the year 2024. In the year OF 2017, General Motors' (GM) uses V2V technology and C-V2X, which utilizes existing cell networks to send data, was initially installed in the Cadillac CTS. This breakthrough makes implementing VANETs interest to several automakers [86].

Audi has an outstanding achievements in VANETs & ITS technology implemented in their vehicles; they started early in 2016 and until now, they are improving these technologies every year in new car models, especially the way the vehicle can communicate with infrastructure as traffic lights to know precisely how many minutes left to change its status from red to yellow to green or vise versa and then provide this information to their cars with a calculated and recommended speed for the driver to drive on to prevent too many stops and anxiety of being able to pass the green light or not, all of this is under V2I. Another technology, V2P, receives warning alerts on the vehicle's dashboard when a pedestrian walking or riding a bike appears suddenly in front of the car or by prediction. Finally, all these technologies are combined in V2X technology to help the vehicle communicate with everything around it to a limit that the car can drive autonomously [87].

A studies found that over 200,000 Americans get injuries every year as a result of people failing to stop at red lights along with drivers are more likely to engage in risky driving behaviors when they experience substantial driving events, such as frequent braking and stops, which may increase their anxiety levels. With V2I communication, Audi cars improve drivers' awareness of traffic and road conditions, which in turn helps them plan their daily routes more efficiently and reduces their anxiety while driving [87].

Since more than 36,000 Americans lose their lives in traffic-related incidents each year, since Audi believes its technology might prevent 6000 of those fatalities, they are actively attempting to make roadways safer [88].

A number of automakers have already integrated VANETs into their cars; for example, Toyota has stated its intention to include V2V and V2I connectivity in all Toyota and Lexus models sold in the United States beginning since 2021. More than 100,000 vehicles outfitted with the V2X technology have been sold in Japan since the technology's inception in 2015. In 2017, the CTS sedan from Cadillac debuted V2V connectivity. V2X, most likely utilizing 802.11p technology, will be available in GM's high-volume crossover beginning from 2023, the company said. Volkswagen started selling vehicles with V2V technology in the first quarter of 2019 [89].

Toyota owns the highest patens volumes in V2V technology from 2010 to 2022 with 119 patents which make it top of the list above Porsche, ford, Hyundai & kia [90]. Improved driver awareness and perhaps accident prevention are outcomes of Toyota's V2X technology, which allows cars to exchange vital information including road conditions and vehicle locations. [91]. As part of its broader dedication to safety, Toyota has debuted V2V and installed driver aid technologies like Lexus Safety System and Toyota Safety Sense throughout practically its entire lineup. Control systems such as radar adaptive cruise control (ACC) already include V2V technology in Japan, according to Toyota. Vehicles that are talking with one another and use this cooperative ACC can safely travel at a closer distance than would be feasible without it. In order for the cars behind to be ready to stop before the radar sensors notice a change in speed, the leading automobile can communicate with them using signals [91].

Two autonomous driving systems, Toyota Chauffeur and Toyota Guardian, are currently in development at Toyota. With the help of an AI system, Chauffeur hopes to one day make it possible for cars to operate autonomously. Guardian, in contrast, is an AI-powered system that aims to improve safety by combining human and machine control of a vehicle in emergency scenarios. To help the driver avoid accidents and other safety-critical occurrences, Guardian keeps an eye on the surroundings and uses a variety of driving techniques. It helps mitigate the effects of human error and environmental variables on the road over a range of capabilities. The end purpose of Guardian is to make sure that accidents caused by human-driven cars don't happen [92].

V2V communication, pioneered by Cadillac, is a giant leap forward in road safety. These communications provide critical road information to other linked cars, including upcoming traffic, speed, position, and direction. Nonetheless, the system does not divulge any personally identifiable information. Full privacy for customers is guaranteed via firewalls and encryption. When activated, the device alerts drivers and their vehicles of impending dangers, such as slick or rocky roads. Additionally, it has the capability to alert drivers of impending collisions, allowing them to adjust their route as needed. In low-visibility conditions, such as heavy rain, thick fog, or nighttime, the device would greatly enhance safety [93]

Wuxi, Jiangsu was the site of Ford Motor Company's successful pilot project in few years ago testing (C-V2X) technology on public highways in China. This is a huge step forward for C-V2X technology, which Ford has been working on for a long time and hopes to improve automated driving, traffic flow, and car safety. Being the pioneering initiative of its like in China, the project showcases a range of V2I, V2V, and V2P capabilities utilizing both direct and network modes of C-V2X technology. Ford is collaborating with local businesses like as Huawei and China Mobile to gather data on driving habits and traffic conditions in China in order to build use cases for these features. To better control traffic and ensure the safety of drivers and pedestrians alike, this technology allows for real-time communication between all parties involved in the transportation network. Important features include warnings when lights are green, red, or amber, as well as suggestions for safe driving speeds and notifications of unforeseen events like accidents or work zones. Further, V2V safety features identify and notify drivers to possible dangers, such as intersection movement assist and emergency electronic brake lights, and V2P. Safety features alert drivers to moving pedestrians and bicycles, therefore reducing the likelihood of crashes. The overall goal of Ford's testing in Wuxi was to further the development and acceptance of C-V2X technology worldwide, which is in line with the company's larger ambition of creating smart cars for a smart world [94].

Improved road safety is the goal of Volkswagen. In North America they did a trial project its primary focus is V2X communication, which links the car to infrastructure like traffic lights, other vehicles, and other road users like bicycles. The goal of the program is to create a system that ensures cyclists are safe by using V2X communication network, which might change the way automobiles communicate to each other and their environment. Better traffic flow, less energy consumption, and, most importantly, increased safety are all possible [95].

Because AI is becoming more important in ITS, Volkswagen has established a new division to research and develop AI named AI Lab that would provide access to various types of AI technologies to be capable to work in ITS such as V2X communication [96]. The table below collects all the car brands mentioned above with the ITS technology they add to their vehicles for improving road safety, enhancing traffic flow and driving experience.

6. Conclusion

The incorporation of ITS within smart city infrastructures is paramount for improving mobility, alleviating congestion, managing traffic flow, and mitigating environmental harm. Recent technological advancements, such as IoT, V2X communication, and 5 G networks, have enabled the deployment of innovative solutions like ITL and VTL. Leveraging real-time communication through 5 G networks and various sensor technologies, including AI cameras, RSUs, and OBUs along with ITL and VTL systems can effectively optimize traffic flow and reduce CO2 emissions.

Furthermore, this paper highlights the importance of addressing security challenges associated with ITS deployment to protect public transit privacy. Through case studies of specific urban areas, it becomes evident that ITS integration plays a crucial role in fostering Sustainable Smart Cities by enhancing driving experiences, road safety, and overall traffic management while simultaneously reducing CO2 emissions and harmful pollutants. The proactive involvement of automotive manufacturers in complying with ITS standards further emphasizes the mutual benefits for both drivers and urban centers.

In essence, the implementation of ITS represents a transformative approach to building more efficient, sustainable, and resilient urban transportation systems, thereby contributing to a cleaner and healthier environment for future generations.

7. Future work

ITS will play a pivotal role in advancing sustainable smart cities, focusing on enhancing mobility, reducing congestion, minimizing emissions, and improving overall quality of life. Several trends are anticipated to shape the future evolution of ITS within the context of sustainable smart cities.

Future ITS will heavily integrate emerging technologies such as artificial intelligence, machine learning, Internet of Things, and 5 G connectivity. These advancements will facilitate real-time data collection, analysis, and decision-making, enabling more efficient traffic management, dynamic routing, and predictive maintenance of transportation infrastructure.

The widespread adoption of Autonomous Vehicles (AVs) is poised to revolutionize urban transportation. As AVs become prevalent, ITS will need to adapt by implementing infrastructure upgrades like smart traffic lights, dedicated AV lanes, and communication systems enabling vehicle-to-vehicle and vehicle-to-infrastructure interaction. AVs offer promises of enhanced safety, reduced congestion, and optimized energy consumption.

Moreover, the abundance of data generated by IoT sensors, GPS devices, traffic cameras, and mobile apps will be leveraged for insights into traffic patterns, commuter behavior, and infrastructure performance. Advanced analytics and AI algorithms will empower cities to optimize transportation networks in real-time, respond more effectively to incidents, and strategically plan future infrastructure investments.

VANETs will enable dynamic traffic management systems that respond to real-time traffic conditions. Vehicles will receive route recommendations based on current traffic flow, road conditions, and individual preferences, thereby distributing traffic evenly, reducing travel times, and minimizing emissions.

Safety remains a paramount concern, and VANETs will support advanced safety applications such as collision avoidance systems, blind spot detection, and intersection assistance. By exchanging real-time information about speed, position, and intentions, vehicles can anticipate potential collisions and take preventive actions, significantly reducing accident risks and enhancing road safety.

Efforts to optimize traffic flow and reduce environmental impact will be central to future ITS initiatives. VANET-based ITS can optimize traffic flow at intersections, merge points, and highway ramps by analyzing data collected from vehicles and infrastructure. Adaptive traffic signal control systems will adjust signal timings in real-time, prioritizing congested routes, reducing delays, and improving overall traffic efficiency.

Additionally, mobile phones equipped with sensors and cameras are expected to serve as inexpensive tools for collecting driving data and connecting vehicles within VANETs and ITS ecosystems. However, it's important to note that cloud system architectures, while effective for data collection, can introduce delays due to latency. Multi-access edge computing (MEC) over 5 G networks is emerging as a better alternative, bringing computing power and storage resources to the edge of the mobile network. MEC has shown fewer delays than cloud systems, enabling real-time decisions and enhancing driver safety.

Integration of Driver Drowsiness Detection systems within ITS ensures driver and passenger safety by detecting drowsiness and alerting nearby vehicles. In Internet of Vehicle networks, vital signals from vehicles are transmitted wirelessly to a traffic management platform, which can trigger alerts to the driver, activate autopilot for safe parking, or warn neighboring vehicles about the drowsy driver.

In conclusion, advancements in VANETs, data analytics, connectivity, and safety systems hold the potential to transform transportation systems in sustainable smart cities. By leveraging these technologies, cities can create safer, more efficient, and environmentally sustainable transportation networks, ultimately enhancing the quality of life for residents. Table 2

CRediT authorship contribution statement

Mohamed Elassy: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohammed Al-Hattab:** Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Maen Takruri:** Writing – original draft, Visualization,

Table 2
Automotive manufacturers adoption of ITS Technology.

Automobile manufacturers	ITS Technology	Achievements	References
I. BMW	• VANETs (V2V, V2C, V2X, V2P & V2I)	• Forefront of connected automobile technology • Enhancement of traffic flow • Promotion of environmental and safety objectives • Revolutionize the driving experience by lowering levels of stress. • Improves mobility in terms of both safety and efficiency	[84]
II. Mercedes-Benz	• VANETs (V2X, V2V, V2I) • Smart Parking	• Enhances both safety and convenience. • Significant step forward in the development of autonomous driving technology • Improvements to both the flow of traffic and the safety of drivers • Ensure increased comfort and safety	[85]
III. Audi	• 5 G • VANETs: C-V2X, V2P, V2I	• Safer Vehicles • more satisfying driving experience • Road safety • decrease the probability of pedestrian traffic accidents. • improve drivers' awareness of traffic and road conditions.	• [86,87]
IV. Toyota	• VANETs: V2V, V2I & V2X • AI	• Improved driver awareness • accident prevention • installed driver aid technologies • Improve safety by combining human and machine control of a vehicle in emergency scenarios. • It helps mitigate the effects of human error	[89,91, 92]
V. Cadillac	• VANETs: V2V	• giant leap forward in road safety	[89,93]
VI. Ford	• C-V2X, V2I, V2V & V2P • real-time communication	• improve automated driving, traffic flow, and car safety.	[89,94]
VII. Volkswagen	• V2V, V2X • AI	• Better traffic flow, less energy consumption • Increase safety.	[89,95, 96]

Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sufian Badawi:** Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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