Intelligent transportation systems

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***Abstract*—The need for safer, more effective, and sustainable transportation options is driving the fast expansion of intelligent transportation systems. These systems cover a wide range of applications, from autonomous vehicles to traffic management and control, with the goal of improving mobility experiences while tackling urbanization issues. Vehicular Adhoc Networks, Intelligent Traffic Lights, Virtual Traffic Lights, and Mobility Prediction are among the essential elements of Intelligent Transportation Systems that are examined in this study, with an emphasis on their role in enhancing sustainability, safety, and efficiency in transportation. It examines recent developments in communication technologies that make it possible for Intelligent Transportation technologies to operate in real time, helping to realize smart cities that are kind to the environment**

I. 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. 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. 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. Intelligent Transportation ITS has a significant impact on how mobility develops in the future due to the continuous acceleration of urbanization and rising demand for effective transportation. In order to create more intelligent, connected, and ecologically friendly transportation ecosystems, governments, businesses, and researchers worldwide are devoting resources to the implementation of ITS technologies. ITS deployment has accelerated recently due to the introduction of technologies like 5G connectivity and the Internet of Things (IoT). Prominent ITS applications include Mobility Prediction, Vehicular Ad-hoc Networks (VANETs), Intelligent Traffic Lights (ITL), and Virtual Traffic Lights (VTL). These are meant to lessen congestion and enhance traffic flow. The goal of this article is to examine how important ITS applications are to the development of sustainable smart cities.

II. ITS TECHNOLOGIES

Vehicular Ad-hoc Networks (VANETs), Intelligent Traffic Lights (ITL), Virtual Traffic Lights (VTL), and Mobility Prediction are crucial components of Intelligent Transportation Systems that drive the smart city transformation by reducing vehicle idle time, enhancing emergency response, improving traffic flow, decreasing collisions, and lowering carbon emissions, with research showing that effective ITS can cut travel times by up to 25% and accidents in urban areas by 20% while also potentially reducing energy consumption and greenhouse gas emissions by 15-20%.

III. VEHICULAR AD-HOC NETWORKS (VANETS)

The Internet of Vehicles (IoV) plays a key role in smart cities by enabling vehicles, infrastructure, and other systems to collect and share data. A major component of IoV is Vehicular Ad Hoc Networks

(VANETs), which support communication between different elements in transportation systems.

There are several types of communication in VANETs:

- Vehicle-to-Vehicle (V2V): Vehicles communicate directly with each other to share data like location, speed, and direction. This helps prevent accidents and reduce traffic congestion through cooperative safety applications.
- Vehicle-to-Infrastructure (V2I): Vehicles interact with infrastructure such as traffic lights, cameras, and sensors. This improves traffic flow and provides real-time updates about road conditions, congestion, and accidents.
- Vehicle-to-Server (V2S): A subset of V2I where vehicles communicate with remote servers. It is mainly used for traffic monitoring and route optimization.
- Vehicle-to-Home (V2H): Vehicles connect with home systems, allowing actions like charging electric vehicles, adjusting cabin temperature, and controlling smart home devices (e.g., lights or doors).

Overall, these communication types work together to improve safety, efficiency, and convenience in smart city transportation system

IV. 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. They gather real-time traffic data using various equipment including cameras, radars and sensors. 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. 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. 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. 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

Vehicles communication in Smart cities

Virtual Traffic lights (VTL)

Virtual Traffic Lights (VTLs) have significantly enhanced Intelligent Transportation Systems (ITS) by leveraging 5G connectivity and advanced road infrastructure, such as cameras and sensors, to detect vehicles and project virtual signals onto the road. These signals are received by On-Board Units (OBUs) in equipped vehicles, providing drivers with real-time information about road conditions.

For example, at an intersection, if one vehicle is moving straight while another approaches from the left or right at a higher speed, the VTL system can detect the potential conflict and transmit a stop warning message to the OBU. If the slower vehicle does not respond, the system can escalate the alert—either warning the driver more aggressively or directly interfacing with the vehicle's automated systems to trigger emergency braking and prevent a collision. A similar mechanism applies to pedestrian crossings, enhancing safety for vulnerable road users.

In addition, VTL systems can prioritize emergency vehicles, helping to reduce response times. More broadly, their implementation at intersections can reduce congestion, improve traffic flow, enhance safety, and minimize unnecessary idling. VTLs are particularly valuable in residential areas or at road junctions where traditional traffic lights are impractical due to narrow street layouts.

A warning message sent to both the pedestrian

Mobility prediction plays a crucial role in the development of smart cities and Vehicular Ad Hoc Networks (VANETs). It has attracted significant attention due to its potential to accelerate autonomous vehicle development, enhance traffic management, and improve road safety. As this technology advances, it is expected to have a transformative impact on future transportation systems.

The primary objective of mobility prediction is to forecast vehicle movement patterns within a network. This involves using various algorithms and data sources—such as historical data, current traffic conditions, and real-time sensor inputs from vehicles and roadside infrastructure—to estimate future vehicle positions and behaviour. Accurate prediction of vehicle locations in the near future is essential for improving the efficiency and intelligence of smart city systems.

Mobility prediction has a substantial impact on traffic management. By anticipating traffic congestion, intelligent systems can proactively respond to bottlenecks in real time. For instance, if a traffic jam is predicted on a specific route, alternative paths can be recommended to drivers, reducing travel time, fuel consumption, and air pollution. Additionally, mobility prediction enables optimization of traffic signal timing. When a system detects a group of vehicles approaching an intersection, it can dynamically adjust signal phases to ensure smoother traffic flow and minimize delays. It can also support dynamic lane assignment on highways by redistributing vehicles across lanes to balance traffic density and prevent congestion.

From a safety perspective, predicting vehicle behaviours helps reduce the likelihood of accidents. Advanced Driver Assistance Systems (ADAS) can leverage mobility prediction to warn drivers about potential collisions, especially during lane changes or merging scenarios. This capability is also fundamental for Autonomous Vehicles (AVs), which rely heavily on predicting the movements of nearby vehicles and pedestrians to navigate safely and efficiently in complex environments.

Mobility prediction further enhances emergency response systems by enabling faster and more efficient dispatching based on anticipated incident locations and severity. In addition, it plays a critical role in mobile and vehicular data communication. By predicting user mobility patterns, networks can optimize data delivery, improving reliability and overall performance.

One key application is in the handover process within mobile networks, where users transition between base stations. Traditional handover mechanisms rely primarily on signal strength, often leading to frequent handovers, increased latency, and potential connection drops. Mobility prediction can improve this process by anticipating user movement, thereby reducing unnecessary handovers, minimizing latency, and enhancing overall network performance. This leads to improved Quality of Service (QoS) and more efficient resource allocation, ensuring seamless connectivity.

In vehicular networks, predicting vehicle trajectories enables better data exchange and communication efficiency. A trajectory refers to the path followed by a moving object in three-dimensional space over time. It can be mathematically modelled, often using polynomial functions, where the direction of movement is derived from the first derivative of the trajectory. Future locations can also be estimated using historical trajectory datasets [28]. By predicting user movement and reserving communication resources along the expected path, network efficiency and data delivery can be significantly improved.

ITS impact on sustainable smart cities.

For the purpose of predicting traffic trends and improving traffic control strategies, the city of Los Angeles has implemented mobility prediction algorithms. These efforts have led to measurable benefits, including reduced travel time and lower greenhouse gas (GHG) emissions. This is particularly significant given that the transportation sector is a major contributor to emissions, accounting for approximately 29% of total GHG emissions in the United States, with emissions peaking in 2021. Between 1990 and 2021, transportation experienced the largest absolute increase in emissions among all sectors.

In 2023, Los Angeles further advanced its smart transportation initiatives by deploying Intelligent Traffic Light (ITL) systems. These systems resulted in a 16% reduction in travel time and a 12% decrease in intersection delays, demonstrating the effectiveness of integrating predictive analytics with traffic control technologies.

Similarly, a 2019 case study in Montreal—a densely populated metropolitan area with approximately 4 million residents—highlighted the challenges of congestion, pollution, and road safety. To address these issues, the city adopted a Sustainable Smart City approach aimed at reducing fuel consumption and carbon dioxide emissions.

Montreal has made significant progress in intelligent traffic management. Approximately half of its traffic signals are now classified as "intelligent," interconnected through a centralized network using fiber-optic and wireless communication technologies. This infrastructure enables real-time traffic signal adjustments based on current conditions. For example, in the event of an accident at an intersection, operators can quickly restrict access to the affected area, allowing emergency responders to reach the scene without delay.

To further enhance incident management, Montreal's Intelligent Transportation System (ITS) incorporates advanced detection technologies. Thermal cameras installed on bridges can identify vehicle presence and differentiate between vehicle types. If a vehicle remains stationary for an extended period, the system automatically alerts monitoring personnel, enabling rapid response. Additionally, Automatic Incident Detection (AID) software leverages existing camera infrastructure to identify moving objects, collisions, and unusual events, further improving traffic safety and operational efficiency.

V. CONCLUSION

The integration of Intelligent Transportation Systems (ITS) into smart city infrastructures is essential for enhancing mobility, reducing congestion, optimizing traffic flow, and minimizing environmental impact. Recent technological advancements—such as the Internet of Things (IoT), Vehicle-to-Everything (V2X) communication, and 5G networks—have enabled the deployment of advanced solutions, including Intelligent Traffic Lights (ITL) and Virtual Traffic Lights (VTL). By leveraging real-time data exchange through 5G connectivity and sensor technologies such as AI-enabled cameras, Roadside Units (RSUs), and On-Board Units (OBUs), these systems can significantly improve traffic efficiency and reduce CO_2 emissions.

In addition, this paper emphasizes the importance of addressing security and privacy challenges associated with ITS deployment. Ensuring the protection of user data and communication networks is critical to maintaining public trust and safeguarding transportation systems from potential cyber threats. Insights from real-world case studies demonstrate that ITS integration is a key enabler of Sustainable Smart Cities, improving driving experiences, enhancing road safety, and strengthening traffic management while simultaneously reducing environmental pollution.

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