IoT-enabled Intelligent Traffic Management Systems for Autonomous Vehicle Integration

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1. Introduction

These high definition maps provide accurate information for objects, lanes, road markers, etc. on the road. High definition maps are generated using the most advanced and precise light detection and ranging (LiDAR) sensor techniques, whose data generation process is very time consuming and expensive. This situation prevents self-driving vehicles from driving in large areas, impeding commercial deployment of these vehicles for the large public at the same time. This paper presents our work combining intelligent connected vehicle technology using our intelligent traffic management system for assisting self-driving cars to safely drive on roadways, without requiring detailed information regarding the roadways over which they are driving. Our system is designed to be compatible with existing standards to allow cars to communicate with the rest of the traffic infrastructure.

Traffic-related fatalities account for nearly 1.35 million deaths worldwide each year, which ranks traffic accidents second, just after heart-related diseases, in the cause of people aged from 5 to 29 years. Injuries from these traffic accidents are a huge humanitarian disaster and lead to a societal cost estimated as 3.71% of the world's gross national product. It is also estimated that self-driving cars have the potential to reduce fatal traffic accidents by more than 90%. As a safety and traffic content company, one of the core focuses is to leverage our technologies to help quickly and safely bring self-driving cars to our global roadways. Currently, one of the limiting factors hindering widespread commercialization of self-driving vehicles is the need for deploying a vast amount of costly, high definition maps, which store minute and accurate geometric information for all roadways where cars will drive. The detailed road information that allows self-driving vehicles to drive safely is stored in these high definition maps.

1.1. Background and Significance

The success of the IoT-enabled intelligent traffic management system is still limited, missing a comprehensive overview for the platform development. When facing practical on-the-road challenges, previously proposed standard IoT-based traffic management systems are generally considered from a small-scale perspective or segmented perspective and have not yet been successfully implemented in real commercial scenarios, meaning that important parts of the standard requirements capable of realistic traffic congestion prediction are still not yet addressed. At the same time, research results dedicated to IoT-based intelligent transportation systems have been robustly proposed from various technical perspectives. The purpose of this study is to design and develop IoT-based intelligent transportation services with larger-scale real data applications to enhance quality and performance with intelligent data capture and information retrieval capabilities.

Intelligent traffic management systems are important for large-scale autonomous vehicle integration, and the development of 5G wireless communication technology provides new possibilities for the wide application of networks in these systems. When large-scale autonomous driving is fully integrated into modern traffic systems, traffic congestion issues will be effectively addressed, and emissions and energy consumption will be effectively limited. Internet of Things (IoT) technology has been increasingly widely used in smart cities, showing versatile applicability in various cities and transportation fields. Most of the related research revolves around the concept of smart cities or smart transportation and has extended the existing work in cities, such as transportation management, environment monitoring, and emergency management. A recent review was conducted for the application of IoT in the transportation field, and it can be seen that existing studies are mainly focused on applications in traffic management, with little attention being paid to providing intelligent analysis for management systems.

1.2. Research Objectives

1) Realizing autonomous vehicle platoons for energy saving, environment protection, and traffic-flow optimization: We aim to propose and develop smart traffic management solutions benefiting vehicles participating in automotive platoons by providing rapid emergency call assistance when needed and ensuring performance improvement during the driving through the establishment of local proxies of the original control station. 2) Advanced vehicle sensing technologies based on cooperative Automated Intelligent Vehicles. Since virtual coupling

within cooperative platooning of autonomous vehicle benefits not only the performance and security of the platoon but also the traffic flow of the entire lanes, we aim to concentrate modeling the diverse complex dynamics with mixed vehicles. Then a game stability criterion is provided to derive the conditions for maintaining the stability under the potential threat of rogue vehicles distributed in autonomous vehicle platoon. In addition, we aim to develop real-time remote/local estimation-based formation control strategies. 3) Providing enhanced vehicle-to-infrastructure communication and sensing and bidirectional communications to enable traffic-management agencies to adapt the controller online for the traffic signals, thus making traffic flow compatible with advanced driver-assistance systems and advanced traffic-management systems. 4) Enabling cooperative vehicle platooning to change the dynamics of urban traffic by allowing vehicles to communicate with each other in real time. This is done in an intelligent and safe manner offering the potential to improve traffic congestion, increase driver comfort, and reduce the environmental impact of traffic. 5) Positioning estimation and lane-level trajectory-tracking control application to autonomous vehicle platooning. In a bidirectional cooperative platooning application of autonomous vehicles on highways, a novel application is addressed in this PhD in the particular area of cooperative vehicle positioning and infrastructure mapping with a single center-located fixed beacon. 6) Safety-critical vehicle conflict detection, identification, and resolution in the roadmap of autonomous driving vehicles. The exploitation of vehicle-to-vehicle and vehicle-to-infrastructure communications to control the conflict detection in the platooning highway applications in a short-range bidirectional communication framework, as well as the implementation of heuristic critical features of the closed greatest lower bound numbers to further safeguard the security of vehicle cooperation.

In much more specific terms, the research objectives are detailed as follows:

This research will investigate the use of advanced IoT-enabled technologies to design and develop context-aware intelligent traffic management systems for achieving seamless and safe acceleration, deceleration, and lane change functions of autonomous vehicles. It is hypothesized that the proposed approach to the IoT-enabled intelligent traffic management system, if realized, will allow cooperative vehicle-platooning to change the dynamics of urban traffic by enabling vehicles to communicate with each other in real time. The overall goal of this research is to contribute to the development of safe, sustainable, efficient, and intelligent urban transportation systems equipped to support the integration of autonomous vehicles operating in large collaborative platoons. We aim to consider both mainstream and relatively less researched problems including positioning and formation control of the Autonomous Intelligent Vehicles (AIV) operating in symmetric and asymmetric vehicle platoons, as well as the estimation of the arrival, queue lengths, and traffic-light control.

2. Foundations of IoT in Traffic Management

In this paper, the focus is on the technical foundations of the traffic management cube that underpins the dynamic traffic management aspects of the I-TraMS. The global traffic cube - as presented for the purpose of smart mobility especially in the framework of the I-TraMS - is made up of five dimensions and three types of cells. The five dimensions are the date-time, the location, the road, the duration, and the reason. The date-time dimension is the prediction timeframe during which traffic congestion, excessive utilization of infrastructure, air pollution in particular areas, or the higher risk of traffic accidents and other impairments of traffic safety and noise can be forecast. They are supported by a set of characteristics that is a small-scale characteristic of the phenomenon covered by the reason. The characteristics facilitate the linking of their associated applications.

Although ITSs have significantly reduced many transportation issues, the increasing global vehicle fleet, traffic congestion, accidents, air pollution, and fuel consumption continue to affect the environment and sustainability. The latest developments in the IoT for the traffic management paradigm, with the infusion of autonomous vehicle (AV) technology, have thus become intensely linked with Smart Cities and Sustainable Urban Mobility (SUM) research. The future struggle is to build upon the advancements of the ITS with IoT-enabled Intelligent Traffic Management Systems (I-TraMS) for the tailored support of communications, collaboration, and pervasive data collecting, processing, and sharing requirements of AVs and other traffic stakeholders. Cutting-edge concepts like triple-helix traffic patrolling are being introduced, where traffic management systems, controllers, and control panels are equipped with artificial intelligence genies that combine machine learning with other advanced analytics that continuously produce and publish in advance to all AV vehicles keeping them road and neighborhood aware in good time. These intelligent traffic wardens have access to the global traffic cubes that are the subject of this paper, where through the IoT they harvest and arbitrate data, forming advanced self-aware, multi-actor, multi-modal, lightweight communication systems.

2.1. Definition and Components of IoT

The Internet of Things (IoT) is an intelligent connectivity of digital devices with trusted people, which empowers them to accomplish a task by using various wireless sensor and node technologies to share information with one another. IoT leverages M2M communication, transforming physical objects into connected devices that can be individually monitored and controlled. IoT includes a range of applications from asset tracking, inventory management and supply chain monitoring to traffic and fleet management. Accordingly, IoT envisions a world where physical objects (e.g., vehicles and smart devices) can be connected to the Internet and collectively share, develop, and execute intelligent services. Key characteristics of IoT services include perception, which enables the collection and exchange of data among various physical objects, and decision making, which encompasses tasks from feedback generation and behavior analysis to cognitive assistance and intelligent perception.

2.2. IoT Applications in Traffic Management

As a scientifically proven concept of making devices interconnected, the IoT allows users to gather a wide range of reliable, real-time and related information from physical objects that will significantly alter how transportation systems are planned, delivered, managed, and used. It also tends to support a variety of interconnected devices, which allowed enhanced traffic protection, traffic flow, and environmentally friendly transportation. In this context, several systems have been created that rely on combined global positioning systems and global information systems that are commonly used in the present land traffic management system. This technology, among others, builds Intelligent Transport Systems, such as advanced vehicle traffic monitoring and management systems, electronic tolling systems, e-pedestrianism, e-parking, e-dynamic monitoring systems and among others. In addition to generating an intelligent transportation system, the IoT allows for the deployment of several logistic support systems and a number of smart-city support solutions. A carefully built road transportation organization will greatly minimize road congestion, cut travel times and improve road transport safety, among its numerous benefits. In order to satisfy the goal of offering its citizens an ecologically sustainable and high-quality life as a smart city, the smart city can use road technologies as one of the incorporation thinks. Nonetheless, until the smart city functions completely, it will be faced with a variety of smart city-related obstacles. It is a billion-dollar challenge to build a smart city. Such impediments include the communication and sharing of knowledge, data management, legal, protection, and risk management, together with software and data security, generally to name a few.

With the growing number of vehicles and road users, traffic congestion is increasing every day. Congestion and the associated negative externalities for road users, such as environmental degradation, waste of fuel and time, and human stress, were the overriding issues for road traffic. Traffic control systems use various applications to stabilize traffic, such as traffic control devices, warning signals, and warning and notification applications. However, these efforts are not entirely satisfactory. Progresses in the fields of information and communication technologies could potentially lead to more effective and efficient traffic management. In particular, one of the most notable accomplishments is the concept of the Internet of Things (IoT), which enables devices to be linked over the Internet and can continually exchange data without human intervention. Although advancements in road transport systems that concentrated on interoperability and integration within other application areas continued to increase, the growing use of autonomous vehicles created a need to reconsider Intelligent Transport Systems. The IoT provided an infrastructure that readily facilitates the collection of accurate, real-time data, which can be analyzed to extract useful and relevant actionable general information.

3. Intelligent Traffic Management Systems

Currently, intelligent traffic management systems (ITMS) are being widely researched and implemented. Nevertheless, as ITMS continues to improve, traditional traffic management systems are faced with the issue of being compatible with the latest traffic management technologies. This problem becomes even more challenging as the next wave of intelligent traffic systems becomes equipped with IoT-enabled vehicle-to-everything (V2X) infrastructure where any type of asset that has capabilities of checking and transmitting the information can send data. Such assets can be traffic lights, parking indicators, and city-owned sensors. These assets and IoT devices are used to solicit the support of the infrastructure on which the autonomous driving system relies, use the location information of nearby vehicles, and provide fusion of sensor data related to road conditions. This intersection between the data and the environment (roadway, buildings, and technology) can enable comfortable and fail-safe autonomous driving.

Smart and intelligent traffic management systems are key for the integration of autonomous vehicles (AVs) within current urban environments. The adoption of Internet of Things (IoT) mechanism in intelligent traffic management systems renders the possibility of exchanging, processing, and acquiring data to enable this new age of smart mobility. Recent research efforts have indicated the potential of sensor-enabled traffic management systems for autonomous vehicle integration. They have outlined the challenges and identified the requirements of traffic management systems for the support of autonomous traffic with emphasis on infrastructure and stakeholder roles. However, there is a lack of attention being explicitly paid to the required transition strategies for existing traffic management systems to become enabled with IoT capabilities while coordinating this transition among all the stakeholders. This paper identifies IoT requirements and transition strategies of intelligent management systems that are needed for autonomous driving and describes scenarios of how these requirements can be expected to vary.

3.1. Components and Architecture

The D-TMC provides services like monitoring, data provisioning, reports generation, policy, and route optimization for traffic dynamics, congestion, accidents, curfew hours, etc. The FIU consists of IoT-enabling devices placed at certain distances on the roads, including Intelligent Physical Traffic Lights (IPTL), Road Signs (RS), and Road Markings (RM). These devices, equipped with Bluetooth low energy (BLE) Beacon, IoT gateway, and IoT server, are powered by relevant IoT devices. The C2 provides an API to interface the proposed Intelligent Traffic Management System (i-TMS) with available autonomous vehicle (AV) services for managed route optimization and additional information. The AVR API services route requests from vehicles through the C2 and the vehicle device controls routing based on policy, traffic dynamics, and other administered aspects by the D-TMC. Ultimately, the prescribed route is followed as per traffic dynamics for achieving Traffic Management Objectives (TMO). The system aligns with major tenets pertaining to green, safe, smart, and adaptive TMO with sustainable Cellular Vehicle-to-Everything (C-V2X) infrastructure deployment, which also facilitates integration of society with IoT services availment, as perceives of Beyond 5G communication infrastructure.

The system consists of five components, namely Infra-vehicle Communication Module (iV-CM), Dynamic Traffic Management Console (D-TMC), Fixed Infrastructure Unit (FIU), Connectivity Cloud (C2), and Autonomous Vehicle Routing (AVR) API. The built-in sensors and IoT devices provide end-to-end communication and response to the infrastructure elements, making the system intelligent for dynamic traffic management. The architecture of the developed system is shown in Figure 1. Every component of the proposed system is described in detail below.

3.2. Key Technologies and Protocols

For fast and secure data sharing, the collected data from each vehicle should be encrypted, and instead of just forwarding the original message, the sender should utilize technologies like secure data hashing and data authentication to send its message signatures as well. The wireless communication media should have multi-function and multi-frequency band capabilities to handle real-time traffic information sharing. P2P or direct vehicle-to-vehicle (V2V) communication is necessary when the network coverage is insufficient or when real-time high-speed vehicle conditions change quickly. Vehicular network communication technologies and protocols should be proactive, rather than reactive, and should include opportunistic network function realization, seamless network access and integration, low latency and real-time capability, secure and reliable information sharing, and message communication efficiency.

To provide on-time traffic information, each vehicle and key station in VSN requires a vehicular communication unit to transmit and receive messages with the surrounding vehicles. Relevant wireless communication technologies and protocols include but are not limited to cellular communication, Roadside Unit (RSU)-based communication, Dedicated Short Range Communication (DSRC), 4G/5G, Vehicle Area Network (VANET), and Peer-to-Peer (P2P) communication. Fig. 1 demonstrates a general VSN architecture for on-time traffic data collection and distribution.

4. Autonomous Vehicles and Traffic Integration

The autonomous vehicle development process, as fast as the legislative point of view and the adaptation of society and infrastructure, has its own critical points that need to be focused. All these points are important for the interaction between autonomous vehicles and the rest of the users of the road network, as well as the integration in the road infrastructure. In this sense, we can highlight the standardization of communication protocols, security and navigation, in addition to the definition of the roles of the different forms of control available in the vehicle. The route and driving of an autonomous vehicle is conducted by algorithms with specific rules and dynamic decision to ensure interaction in the environment, by defining control flows and deadlocks. In order to install autonomous vehicle systems, the condition of the environment for the vehicle operation in these environments must be guaranteed for its operation.

The development of autonomous vehicles has been growing in recent years, although this issue is not a new concept. The work developed by companies like Mobileye or Neodriving to assist car driving is an example of development towards the autonomous vehicle. Despite being some specific companies that have been drawing and developing autonomous vehicles, we have also been seeing and analyzing the development of autonomous vehicles as an already regular means of transport on a regular basis in normal road conditions, carrying out trips in the city and/or the highways.

4.1. Definition and Types of Autonomous Vehicles

- Level 0: No Automation: the driver performs all driving tasks. - Level 1: Driver Assistance: a single automated system is provided for specific tasks, which are performed by the driver during vehicle operation, such as steering and parking assistance, adaptive cruise control, lane keeping, and self-parking. - Level 2: Partial Automation: the driver has to monitor the vehicle and perform all driving tasks, with the help of two or more active systems, such as adaptive cruise control, lane centering, or parking assisting. Independent operation of all lateral and longitudinal control mechanisms is also possible. - Level 3: Conditional Automation: the system takes over all driving tasks during specified driving mode conditions or in specific environments. The driver can read or look away from the road. - Level 4: High Automation: the vehicle can drive automatically under defined conditions, while the system handles all driving tasks and can intervene in specific situations with additional driver assistance. - Level 5: Full Automation: the system handles all driving tasks and can intervene in all potential emergencies with driver assistance. The vehicle can drive automatically under all driving conditions.

At present, several types of autonomous vehicles can be distinguished. The Society of Automotive Engineers has classified these vehicles according to the degree of vehicle automation. This classification was officially adopted in the USA as part of efforts to standardize vehicle automation. Classification is based on several aspects: the level of human participation in vehicle operation; the complexity of automation (number of functions provided); and the number of vehicles controlled by the system. This classification differs from earlier ones in terms of the level of automation; in particular, it includes several intermediate automation levels above the partially automated level. These levels are described as follows:

4.2. Challenges and Opportunities for Integration

Challenges and Opportunities for Integration The design of the transition system from a non-automated traffic system to a fully CV agnostic ITMS involves special considerations. Both transportation and communication technologies require careful planning and phased deployment. Policy statements and regulations from federal and local governments are highly required for maintaining security and privacy. The public infrastructure faces severe budget constraints. The automotive industry negotiates shared platform and data coupling policies. The public-directed changes have to genuinely benefit all citizens. The public data have to be protected from fraud, cyber-attacks, and abuses, while at the same time ensuring the reliability of the ITMS services. The ITMS has to be developed and evolved from an architecture that is tightly affiliated with the installation of autonomic vehicular services.

To tackle unique transportation challenges and achieve the potential of context-aware, self-driven vehicles, a fully functional ITMS must be developed to support integration with CVs. Beyond these essential features, a successful ITMS should be intelligent, seek synergy and inclusiveness, enable matchmaking, go towards fairness and cost effectiveness, and further take advantage of the spatial computational capacity of edge computing to ease the data analytics and artificial intelligence. We have advanced these five features and explored their potentials to provide everything from an immediately deployable solution to a future-oriented visionary system.

5. Case Studies and Best Practices

Case Study 5.1: IoT-Enabled Privacy-Preserving Vehicle Platooning at Urban, Interurban, and Highway Speeds: The case applies a secure and privacy-preserving IoT-based infrastructure-on-board communication platform to realize highly efficient and long-range multiple-lane urban, interurban, and highway-speed vehicle platooning. The use of a real map of vulnerable pedestrians and cyclists ensures that it is always fully visible to a vehicle platoon and vice versa, so that no platoon-related crashes with vulnerable road users can ever happen. The proposed secure and privacy-preserving multi-physics platoon-on-map IoT architecture ensures that roads are shared, not overused; crowded assistant-activated smartphones leave with happy car drivers. If autonomous vehicles enable lower safety distances than 2 seconds in bumper-to-bumper traffic jams, then this can be observed for free within the overall control loop of investing in infrastructures or sharing them with short-term profitable positive external effects.

This section highlights various application scenarios, case studies, and provides guidance on best practices and key lessons learned for implementing intelligent transportation systems using an IoT platform to enable autonomous and cooperative decision-making processes across infrastructure and mobile traffic entities.

5.1. Real-world Implementations

iii. New York City Department of Transportation (NYCDoT): In New York, the traffic management system used is called TOPS and is managed by the NYC Department of Transportation. Since 2003, contractors working on behalf of the NYC Department of Transportation (NYCDoT) have been systematically reporting speeds via GPS observations twice per day, in approximately one-hour intervals near 6 a.m. and 3 p.m. The GPS observations were collected year-round on weekdays between Jan 1, 2003, and Dec 31, 2009, and contain six types of recorded data: Average speeds on city streets and expressways (second) heading into Brooklyn, Queens, Manhattan, and the Bronx, and Average speeds on approach freeways heading into Manhattan, as well as the date and time data.

ii. IceTel: IceTel Real-time Intelligent Traffic and Energy Management Laboratory, which is an experimental research facility consisting of an educational Traffic Simulator and different advanced detectors developed in both traffic and meteorological management fields. The detector based on video analysis, Infrared, and LIDAR sensor used provides an accurate, low energy consumption traffic monitoring and forecasting service. The data automatically collected by a network of different installations analyze and synthesize for a Real-time Traffic and Weather Management.

i. Rome Traffic Control Centre (RTCC): Also referred to as Infomobility Rome, has been serving the citizens of Rome since 1997. Infomobility is the Rome Traffic Control Centre (RTCC) service that provides real-time information on traffic, parking, public transport, and local public authority services. The main aim is to ensure that information is available to users from all of the information channels (telephone and internet services for the general public, radio and video services aimed at motorists), and that it is targeted accurately and transparently.

With the advancement of technology, more and more intelligent traffic management systems are being proposed, which aim to optimize the use of the existing infrastructure to support traffic mobility by making autonomous traffic management decisions. Some of these systems are currently in use and provide us with real data to evaluate the impact of our proposed AV integration framework. In this sub-section, we will present data from four state-of-the-art ITS for thorough evaluation of our proposed framework, as shown in Figure 7. These systems are:

5.2. Success Stories and Lessons Learned

For each of these deployments, smart city IoT system architectures are provided. The role of the system is to facilitate management in order to create a responsive city able to dynamically adjust services to fit the citizens' and city environment requirements. If the services for the denizens involve the use of autonomous vehicles or similar electronic AI-enabled systems, these systems must be able to interface with and operate within this mature IoT-enabled capability. By utilizing the common operating framework and interfaces provided by the IoT-enabled infrastructure deployed in these cities, new startups can focus their resources on the development of the potential of autonomous vehicles. Additionally, the availability of test beds would significantly reduce the time it currently takes to progress any design through the stages of development and testing of autonomous vehicles. As many fleet learning kilometers are required to develop the design parameters of vehicle-on-vehicle interactions, environmental perception sensors, and maneuvering, the use of test beds becomes paramount.

A number of cities around the world have made significant progress in implementing traffic management systems comprising ICT and IoT-enabled infrastructure. They have demonstrated the ability to manage traffic volume in a variety of contexts covering CBDs, residential areas, and streets within large campuses in order to maintain traffic flow, safety, and provide priority parking. A considerable amount of IoT spatially distributed traffic management infrastructure and sensors, together with software systems, are deployed in large cities. As operators in these cities have gained significant experience in dealing with various traffic situations, they have developed advanced traffic management systems which have been able to reduce traffic congestion, travel time, and pollutant emissions. They provide a foundation for test beds that would be used to validate electronic systems of autonomous vehicle startups; and also evaluate the effectiveness of autonomous vehicle deployments in a variety of traffic situations.

6. Security and Privacy Considerations

However, security and privacy provisions without adequate assurances can affect the interoperability, accountability, and dependability of autonomous automotives. Openly, coercion of security, privacy, and resilience decreases in the degree of gamification acceptance of the system and architecture, which again affects the trustworthiness of the system. Hence, a trusted space which bounds trusted values and trusted models are required without compromising the security and privacy settings of vehicles participating in the traffic management system. The assessment for data trust and value will be different based on the data sources and related confidence in and which kind of environment the data points originate. The machine learning models that process these sources are also required to be tested.

Security and privacy are crucial components of any system, ensuring that the system has data confidentiality, data integrity, and user privacy. As intelligent traffic management systems are dependent on the IoT infrastructure, the security of the system is of immense importance. Autonomous vehicles contain minimal hardware that can organize high-level security and privacy treatment supported on generations of cryptographic techniques. Deployment of the intelligent management system can either be only vehicles-based or the vehicles and sensor infrastructures, combinedly managed. IoT-enabled vehicles provide real-time data of traffic, not only for themselves but also for the entire road network, nearly instantaneously to traffic management systems. This strategic upgrade of the infrastructure can be a tedious task, and it is expensive to handle the vast amounts of data being collected.

6.1. Threats and Vulnerabilities

The detailed location, status, and trajectory data need much processing for protection. For example, mobility data of drivers, passengers, and fleets can be collected and analyzed by TMS operators, public safety departments, and third-party companies, presenting substantial privacy threats. Furthermore, through exploiting vulnerable vehicle onboard components, malicious attackers can remotely control a victim's vehicle, and this can result in unauthorized access to the vehicle, advanced theft schemes, as well as critical safety threats. On the other hand, attackers can threaten the performance of AVs by directly transmitting illegitimate command/tracking electromagnetic signals or tampering with communication and neighbor discovery between AVs. With the malicious behavior of AVs, the reputation collection for AVs and study on the proposed geographic location applications could be affected.

In the IoT, the majority of the security vulnerabilities are due to the heterogeneity and distributed nature of connected devices. Hence, of primary concern in IoT security are the handling of IoT device access control policies, IoT networking, and intruding procedures. In the same way, the intelligence from AI and the IoV/DoV in the TMS for AV integration can make traffic information more efficient and provide better services, the integration also brings security challenges. On one hand, many parties are involved in providing traffic-related services, which includes but is not limited to vehicle end-users, vehicle manufacturers, service providers, and infrastructure management authorities. The envisaged capabilities of IoV/DoV are supported through data provided by a range of different data sources including infrastructure and in-vehicle sensors, other vehicles, traffic management centers (TMC), and other information sources.

6.2. Mitigation Strategies

For ITMS, containment is also a key consideration in that a network intrusion-detection system should be able to identify the source of a cyber-attack caused by a particular cluster, vehicle, or IoT device connected to the network. This can be supported by the use of Multilateral Traffic Management Protocol (Multilateral Protocols). Similar to this type of protocol, it can also be used to inspect data flow through IoT devices that another IoT device sends data through. Intrusion-detection endpoints in a data-share protocol may enable authorities to quarantine affected vehicles or intervene on it while in transit. When needed, tightening the transmission of data from a device may influence the composite device to transmit constructional sensor information rather than disinformed information. A cost and a risk analysis will be necessary to determine the tranche of infected devices and their economic impact.

To mitigate an attack on an ITMS, we need to ensure that, in the event of detection, we can quickly and effectively take response actions. Along with the endpoint security strategies that are inherent to the involved embedded systems and devices, such as authentication, authorization, and data protection capabilities, we can enable extensive logging and monitoring of critical components of the ITMS and enforce careful adjustments of both firmware and software updates to reduce the rapidly evolving exploitation capabilities of cyber-attacks. Security products, techniques, and teams are no longer limited to computers or web applications, and as connected devices permeate additional areas of our personal and work lives, available countermeasures must expand accordingly.

7. Regulatory and Policy Frameworks

In the philosophy of technology literature, regulatory and policy kinds of interventions are often given less attention in preference to those interventions focusing on the development and design of the technological system or choosing one certain technology. If this autonomous vehicle technology has the potential to create significant social transformation and create several nontrivial benefits in safety, congestion, emissions, and access, governments or regulators have multiple means at their disposal to promote or inhibit the social adoption of autonomous vehicles. These means focus on technology regulation, regulation of inputs, direct procurement, ownership, and operation of autonomous vehicle services, land use policy, intellectual property policy, liability or accident law, socioeconomic policy, and energy and environmental policy. These regulatory or policy measures take place before a certain autonomous vehicle technology is introduced, while the vehicle is produced or sold, and after the vehicle is used on the road. For these regulatory or policy measures, they take the so-called pre-regulation, regulation, and ex-post regulation processes. The terminology of these measures is developed in conjunction with amendments or new legislation decisions.

The future of automated driving holds the promise of nontrivial social benefits. The pace and extent to which these benefits are actualized is significantly contingent on a host of factors that include technology development, systems innovation, regulatory, and policy frameworks. This chapter has introduced a series of intelligent traffic management systems offered by Internet of Things (IoT)-enabled intelligent infrastructure to enable a safe, efficient, and effective integration of connectivity and automation. These systems are classified into traffic information production, dissemination, and traffic capacity management using high-frequency data analysis. The effectiveness of these IoT intelligent traffic management systems is demonstrated with plausible examples. The potential impact of privacy preservation and cybersecurity as well as the potential validation of these IoT intelligent traffic management systems under platooning operations for autonomous vehicles are discussed.

7.1. National and International Standards

Even these are more stringent in the case of signaling and control of modern vehicles such as buses, automobiles, and vans, because they assure that there is satisfactory determinism even in adverse weather conditions and visual noise in green, red, and yellow color signals typically located at the sidelanes, pedestrian lanes, and bus advance signaling. Therefore, under these standards, everyone is permitted, in principle, to rely on and behave accordingly and safely, because if something unusual happens, the brakes and smart sensors could guarantee the proper safety maneuvers. This element is the fundamental basis of intelligent traffic control, encouraging potential positive impacts on every personal driver and fleet operator conduct behaviors. In the case of autonomous vehicles, the behavior is similar, but the control mechanism is improved to guarantee automation. Any potential conflict is overcome by the automatic safety reaction.

The advance of use, improvements, and application of IoT-enabled intelligent traffic management systems for integration in comprehensive models of safe, secure, and sustainable transportation of people and goods requires compliance with some minimum specifications, criteria, pneumonics, measures, etc., in such a way as to guarantee that any interoperability, performance, signaling, and design of proper interfaces and equipment calibration are in agreement. All these technical aspects also contribute to the security of the utilized identification processes adopted by possible hostile people, gangs, or terrorist groups. These propositions start embracing signals, controller systems, electronic interfaces, data interchange, etc., appearing in national and international regulations and standards.

7.2. Legal and Ethical Implications

Real-time information is impressively useful, but at what cost? Conversely, if a vehicle that is transporting an injured person to the hospital, the last thing it needs is delays. For autonomous vehicles, more general ethics discussions, Carlini and Wagner even use novel techniques from optimization theory in order to address the demand of pressure in the autonomous vehicle age and incorporate run time guarantees into their systems. However, the lack of responsibility in cases such as Uber was the subject of much conversation online even after the letter of the law placed the "responsibility" – such that one can even make it a responsibility – at the feet of the individual who was not driving the car. With the current traffic management systems, there are logistical issues that can make it hard to be held responsible, but when this is less and less the case, responsibility becomes a very important question. Minimally, it becomes easier to do so.

This technology will be forced to consider similar ethical considerations, such as public safety, to extend this. A regulation such as ECOM will impose a lot of security type method for managing and securing data. ECOM aims to address some of these concerns with the IoT. Their question was "Why and How" over "if" these regulations should be placed whereas here the questions might change to "Are they being adhered to?" and "How are they adhering?" In terms of traffic management, the more automated and seamlessly data and communication occur, the safer and more efficient our transport will be. When these systems have the power and capability discussed in this chapter, they come into a whole minefield of responsibility. For managing traffic, these systems are willingly sending information around the world and back to a wide range of enable faster traffic flows while not controlling the capabilities of transportation.

8. Future Trends and Directions

The other desirable trend is described as emulating the private sector. Sometimes the most effective leverage of public resources can come from more thoughtful partnerships and agreements with private businesses who have their own facilities, budgets, and other available resources as part of their business. A private-sector firm that usually already has a networking business (e.g. trucking, tow trucks, etc.) and some of its users on the road network can recognize the benefits from having unique data or data usage capabilities. The remainder of a more advanced traffic management system is defined by who the users might be and what kinds of data might be available if more users and databases are collectively asked if they and the data might be contributed to the project. The traffic management center that can recognize the potential benefits from computer and communications technologies can convince a few key partners to provide some resources to jointly develop the system.

One of the desired trends, brought about by tackling any of the challenges listed earlier, is to develop traffic management systems that can predict delays on specific roads and streets and change traffic light patterns to manage and reduce the severity of the delay. The next trend is anticipation and preparation. Their relevance often depends on the advanced traveler information systems and other technologies that are part of the "trip planning" trend. However, the event management trend focuses on the actions of traffic managers, not travelers. When devices used by people or in infrastructure can provide information of use during an incident, it is also possible to detect the incident, and new automated processes are then possible. In addition to the three traffic management functions identified. This is essentially the elimination of congestion using these other transportation management and demand management methods.

8.1. Emerging Technologies

To support autonomous vehicles and integrate driving functions, advanced sensors are used to detect specific road conditions. LiN Transceivers are the core technologies used in detecting obstacles and minimizing accidents surrounding unmanned vehicles. They can simultaneously detect position information of various target objects. Navigation and control technologies necessary for the autonomous and intelligent operation of vehicles are one of the active research areas due to factors such as large automobile size, narrowing roads, and environmental research opportunities. Moreover, research on V2I technology, which includes the security of self-driving and smart transportation, is needed. The vehicle communication technology currently in use is exposed to various attacks such as jamming and man-in-the-middle attacks in the communication process. It also frequently uses a broadcast-based process, threatening user privacy. Due to exposed risks such as system security, huge traffic congestion research is needed.

Infrastructure technologies within smart cities, such as advanced sensors and IoT software, support more data-driven and intelligent transport services. These services are not only intended for better vehicle support systems but also for autonomous vehicles, which was not originally anticipated. The design of future transport systems, which make increasing use of AI, 5G communications, IoT sensors, and big data, will need careful regulation to ensure alignment with their intended objectives of improving the sustainability of the transport system.

8.2. Potential Impact on Urban Planning

Cities create traffic by allowing diverse land uses instead of creating multifunctional neighborhoods. For example, people travel on average 6.4 km to shop for food and provisions. Planning codes create separation between land uses, which thereby induces the need to travel as people are unwilling to shop in diverse areas. By creating more mixed-use neighborhoods, people are able to walk or cycle short distances to shops and services, which increases the use of non-motorized transport (potentially including bikes and scooters used as part of multi-modal trips made by connected autonomous vehicles). The effect is to increase the critical mass of residents and proximity of supporting businesses, prune fat from local transportation systems, reduce the need for large parking lots, and replenish resilience to communities. Such developments support social and environmental sustainability while attracting innovation, employment, and experience. The short-distance travel implications of housing location choices suggest that walkers, bikers, and public transportation (microtransit) users will benefit from the transformation of residential areas near high-frequency mass transit lines.

The extensive use of connected autonomous vehicles will result in a reduction in the number of vehicles on the road and the amount of road space necessary for moving people and goods. This will, in turn, allow cities to re-utilize large amounts of land currently dedicated to parking and streets. Efficiently reducing car use with the carrot of autonomous vehicles may result in fewer challenges to urban development than using the stick of increased road-user charges. For instance, cities like Curitiba, Brazil, have been able to transform some streets into green parks while still improving traffic flow using its bus-based public transport system. However, re-purposing land in topographically/sociodemographically non-homogeneous areas will result in cars being parked farther away from key activity nodes, removing the convenience of door-to-door transport that is generally provided by owning a car. While buses/ride-share will be able to remove this inconvenience to a large extent, ensuring the success of such a system will require a transformation of the urban planning paradigm that is currently dominated by the car.

9. Conclusion and Recommendations

This is a first step in an exciting and significant direction, and many remaining research topics in this area deserve further study. The field of traffic management is large, and most of the research at this stage will focus on the information exchange of vehicles with the road infrastructure. First, the core of future traffic management systems is in the exchange of such information. The accuracy of this information will be an important factor in the future transportation network. Although the realization of various information exchange schemes is highly anticipated by the realization of future transportation networks, it is far from solving various technical problems such as the floating car data problem and the road link identification problem. Second, other challenges include the powerful use of IoT devices in the network environment. These and other topics are becoming more challenging with the growing urbanization of populations, leading to ever-increasing demands for improved traffic management. Given these and other growth prospects, future systems that harmonize human drivers and vehicle autonomy, i.e., IoT-enabled traffic management systems, are important in helping to contain congestion and improve the quality of experience of transportation networks.

As we approach the era of autonomous vehicles, Intelligent Traffic Management Systems (ITMS) will become a critical technology in facilitating the integration and deployment of autonomous vehicles into transportation networks. In this paper, we propose an IoT-enabled intelligent traffic management system for this purpose. To illustrate the ITS concept, we propose and design two innovative examples: an IoT-enabled traffic light system and the road-vehicle-cloud communication via traffic lights. This paper discusses the applications of these two examples in the transportation network and the potential benefits.

9.1. Summary of Key Findings

In this book, we have presented our study towards the realization and implementation of an IoT-enabled Intelligent Traffic Management System. The research was done in different stages, necessitating the utilization of a multidisciplinary approach and enabling the realization of an end-to-end framework needed for managing future autonomous vehicle urban mobility. In these regions, infrastructure deficiency may not allow the deployment of high-level autonomous vehicles solely based on their integrated sensors. Cooperative systems can enable these vehicles to communicate with the infrastructure, other vehicles, and infrastructure to vehicles. Devices can also be used for cooperative perception purposes to assist the autonomous pavement construction machines with real-time convergence to the reference geometry.

In this book, we explain that IoT technology represents a critical enabler for intelligent urban traffic management systems that optimize traffic flow related to existing transport infrastructure, but also better integrate autonomous vehicles in society. In several cities, traffic jams and air pollution are serious problems. Moreover, in some developing countries, additional issues such as poor road surface condition and broad fluctuations in traffic density, including from other modes of road transportation, may lead to road accidents. In a time of ever-growing urbanization, combined with the increasing demand for urban transportation, investment in road transportation infrastructure becomes challenging. Therefore, countries should pay high attention to the development of Intelligent Traffic Management Systems (ITMS). These systems make use of Internet-of-Things technologies to enable traffic flow optimization, and thus enable the efficient use of existing transport infrastructure, for both the present (human-driven vehicle) and future (autonomous vehicle) scenarios.

9.2. Implications for Future Research

Further pioneering research should explore the new business model for leveraging IoT solution innovations' potential value. The introduction of autonomous, electric, and connected vehicles to the streets will significantly change conventional notions of mobility through data flowing through numerous technologies to boost safety, efficiency, and accessibility. While advances in technology continue to accelerate the development of smart city applications, we have not really developed a business model that properly catalogs patterns of value creation. Furthermore, as the technology of IoT advances and new opportunities emerge, the monitoring and control of all IoT small and large systems will become significant in all engaging IoT systems. We believe that the new business model will enhance growth. Many present cities and public transportation systems will be strongly influenced and transformed by such models in the future. Such business model evolution will have a critical strategic effect on vehicle manufacturers (Original Equipment Manufacturers, OEMs) and serve as a means of differentiation and diversification. They could also offer profitable returns on IoT investments.

This study provides a comprehensive literature analysis of traffic management systems that have addressed the integration of an innovative traffic management system based on Internet of Things (IoT) technology utilized in an autonomous vehicle, enhancing the concept of artificial traffic flow in the smart city. This research explores the roles of service platform, service layer, transparent communication, application layer, and decision-making support in IoT traffic management services. Based on unique methodologies, interfaces, and information technology, this study develops an IoT-enabled Transportation-Define, Measure, Analyze, Improve, and Control (DMAIC) system, which can provide traffic monitoring, short-term traffic congestion prediction, dynamic road surface quality monitoring, and provide the decision-making support to improve and control traffic problems allowing large numbers of autonomous vehicles to travel freely. The platform for traffic safety incident analysis (T-DMAIC) is developed for decision-making support. T-DMAIC provides real-time event backtracing ability for operations and interface capability for traffic managers. The extensive mobility aspects ensure the quality of service for the autonomous vehicle infrastructure. Additionally, developers of T-DMAIC can use the provided service interface to enhance their own IoT traffic management services.

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