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Research Article

Internet of Things-Aided Intelligent Transport Systems in Smart Cities: Challenges, Opportunities, and Future

Khaleel Ahmad[1], **Halimjon Khujamatov**[2], **Amir Lazarev**[2], **Nargiza Usmanova**[2], **Mona Alduailij**[3] and **Mai Alduailij**[3]

[1]*Department of Computer Science and Information Technology, Maulana Azad National Urdu University, Hyderabad, India*
[2]*Department of Data Communication Networks and Systems, Tashkent University of Information Technologies Named after Muhammad al-Khwarizmi, Tashkent 100200, Uzbekistan*
[3]*Department of Computer Sciences, College of Computer and Information Sciences, Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia*

Correspondence should be addressed to Mai Alduailij; maalduailij@pnu.edu.sa

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The world's population is growing rapidly, and population management processes have become much more complex. The world's population lives mainly in cities, and naturally, the governance processes in cities are increasing. For efficient process management, researchers are now proposing smart city concepts. According to this concept, research work is being carried out in several directions. One of these areas is an intelligent transport system. This research paper discusses the scientific work performed in intelligent transport systems, including concepts, capabilities, Internet of Things of vehicles, organization of information, and communication processes. The operating frequency ranges, network parameters, and applications are considered. The final part of the paper presents a proposal for creating an intelligent parking system and outlines some promising work that can be done in this area. This paper is intended for researchers who plan to explore important aspects of intelligent transportation systems and help them in their future endeavors.

1. Introduction

Cities and urban centers have become the driving force behind the development of the economy and the cornerstone of industries such as manufacturing and consumption lately. In general, cities play an important role in national, regional, and global development, and 60% of the global population currently lives in cities, as shown in Figure 1 [1]. Since the problems of urban resource management have become a complex task, it is necessary to search for the concepts of urban management. One of the concepts of managing such cities is building a "smart city."

The smart city is a concept of urban planning for urban infrastructure management, which integrates various ICT (information and communications technology), including the IoT [2–4].

ICT allows urban infrastructures to interact with the population and urban infrastructure and to observe what is happening in the city, how it develops, and how the quality of life improves. Using IoT systems in a smart city, real-time information transmitted by sensors is processed and analyzed. Based on the results obtained, efficiency problems are solved [5].

2. Functional Areas of the Smart City Concept

The smart city concept is designed to develop public services, energy, transportation, health, water supply, agriculture, and waste disposal. Table 1 illustrates the smart city concept.

Table 1 lists the main areas of energy, transportation, water and gas supply, and building management. Each section provides comprehensive solutions for optimally developing the "Smart City" concept [6].

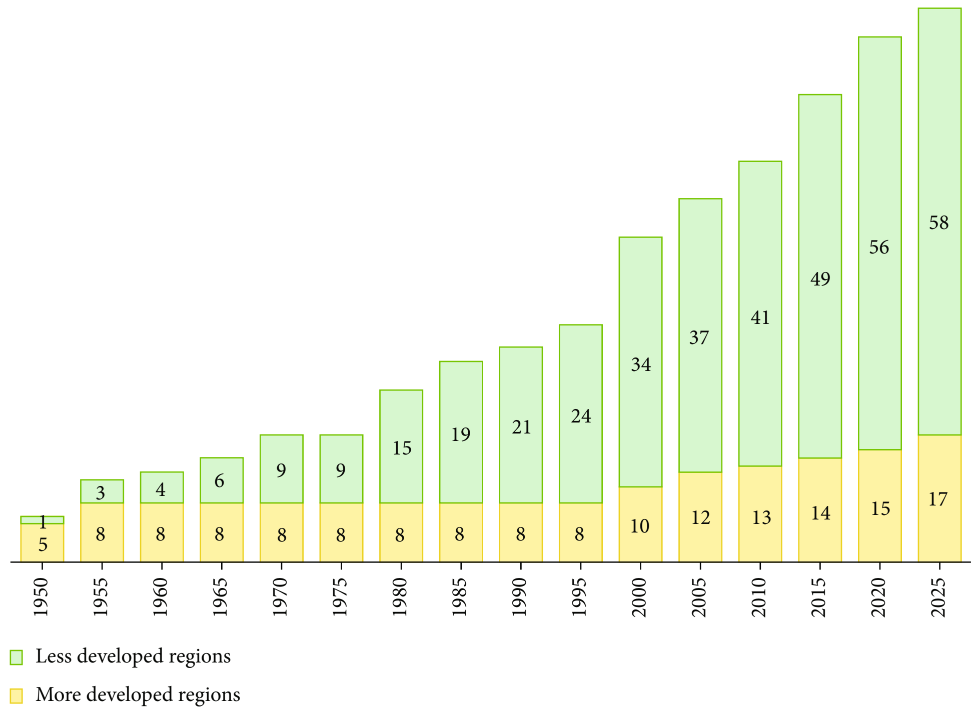


Figure 1: Number of metropolitan areas with a population of 10 million or more [1].

Table 1: Functional areas of the smart city concept.

Smart grid	Smart transport	Smart gas and water	Smart urban environment	Smart home
Energy consumption meters	Intelligent transport systems	Water consumption meters	Video surveillance	Integrated automation
Manage the end point of spending	Infrastructure payment systems	Water consumption management	Lighting	Remote control of building and house
Electric transport infrastructure	Smart parking	Determining water leakage	Waste recycling	Smart techniques
Integration of distributed generations	Dashboard	Emergency management	Urban Management	Smart applications and IT services
Coherence	Low carbon dioxide emitting vehicles	Reduce water leakage	Effective hospitals	Design of energy-efficient buildings
Regenerative generation	Ecological public transport	Innovative methods of water treatment	Social services	Restoration of energy-efficient buildings

Since the “Smart Transport” direction in the concept of a smart city is the subject of the paper, this section will be discussed in more detail below.

3. Literature Review

In the class of these systems, one can single out a set of intelligent transport systems (ITS) that are distinguished by the ability to carry out an automated solution of the most complex, difficult-to-formalize, high-dimensional computational, logical, and management tasks, for example, forecasting traffic flows on a complex road network using incomplete initial information, optimizing the routes of vehicles and developing optimal control actions for traffic control tools, taking into account the predicted traffic situation, extracting implicit patterns from large arrays of data on vehicle movement, etc.

In several publications, the following properties are given, which make it possible to classify a technical system as an intellectual one:

(i) *Learnability*. The ability to generate new knowledge and data (models and decision rules) based on the mechanisms of inductive inference, generalization of statistical data, etc.

(ii) *The Ability to Classify*. The ability of the system to independently differentiate control objects, environmental influences, control signals, and automatically structure data

(iii) *Adaptation*. The ability of the system to adapt to the changing conditions of the operating environment, correctly take into account the nonstationarity of control data, etc.

In addition, the following are some of the works that were done by the researchers.

The authors developed the computer vision methods used in roadside cameras of ITS, and the proposed method is suitable for the security field of ITS. Because in this method, the functions of vehicle classification speed determination are performed. This method can be used by authorities to develop and monitor roads [7].

The authors suggested an architectural framework for processing, storing, collecting, and integrating information in an urban transport environment. The proposed architecture helps to make decisions through the use of intelligent processes in order to optimize vehicle traffic in real time [6].

In this paper, the authors considered the issue of ensuring the quality of service provided to the traffic of V2X (vehicle-to-everything) applications in the networks of intelligent transport systems by distributing computing loads between servers and selecting the parameters of data distribution. Theoretical results are obtained in this work, which allows V2X applications to reduce the resources of communication channels and the time of computational processes in operators' service [8].

This paper examined methods and models for managing widespread traffic distribution in self-contained VANET (vehicular ad hoc network) wireless networks for road safety systems. This study also obtains theoretical results and can be used in road safety applications in intelligent transport systems [9].

In this paper, the authors studied selecting intelligent parking lots based on simulation modeling and static analysis of transport networks. They developed a software and hardware system of intelligent parking in the form of a smart city terminal. The difficulties raised can be exploited to develop an intelligent parking system [10].

In this paper, the author discussed the optimal control of autonomous vehicles in an intelligent transport system to classify traffic patterns and obstacles. The results obtained in this dissertation work aim to optimize traffic flows using autonomous vehicles through V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) communication [11].

The authors analyzed complex problems in the intelligent transport system, such as the highly dynamic VANET network, the interaction of infrastructure with road transport, machine learning, energy-saving RSU, design, and other issues were studied. As a result, further research areas are highlighted [12].

The authors developed an algorithm to estimate and predict travel time on urban and interurban roads. This work takes into account the existing barriers between the cities, and the results obtained will be useful in choosing the shortest route for travelers [13].

This paper proposed a 5G-based SDN (software-defined networking) architecture for intelligent transport systems, allowing for expanding the capabilities of intelligent transport systems. Theoretical results on the proposed architecture have been obtained and can be applied in subsequent intellectual systems [14].

The authors focused on the reliability of packet transmission in automotive networks. It examined the performance of automotive communication systems in different scenarios and proposed a model for the analytical determination of packet transmission reliability for the selected communication channel. The obtained results are useful in determining communication parameters, service quality requirements, density, and speed of vehicles [15].

In this paper, the authors studied large-scale data analysis in intelligent transport systems that can predict traffic flows [16].

This paper proposed a VCom (virtual comp port) protocol to ensure the security of vehicle information exchange processes. It provides theoretical results and reduces communication, calculation, storage, and energy requirements [17].

The authors proposed a blockchain-based SmartCoin mechanism to increase the reliability of vehicle information. The proposed mechanism is aimed at social welfare, reducing traffic congestion, road safety, and preventing false messages in the vehicle network [18].

Research conducted by the researchers on the above and intelligent transport systems focused on road safety, data processing, autonomous vehicle management, and the interaction of road users.

4. IoT-Aided Concept of the Intelligent Transport System

"Smart transport" is a complex technological solution for interconnecting all vehicles and infrastructure systems. Using this communication system, it is possible to fully identify the condition of road sections and control the flow of traffic using data from mobile operators and GPS signals [19].

Transport volumes are growing uncontrollably in cities worldwide, with delays, congestion, the appearance of routes, CO_2 (carbon dioxide) emissions, accidents, emergency services, and theft of public life as a result of growth. The Texas Transportation Institute wasted $160 billion on electricity due to traffic congestion [20]. According to the United Nations Relief and Works Agency [21] and the Population Reference Bureau [22], worldviews are growing, and people are moving to cities. Thus, there is a vital measure to ensure the efficiency and safety of traffic.

Successes in ICT can help meet this need. Intelligent transport systems (ITS) assist in integrating ICT with transport infrastructure. The basis of ITS is the data that needs to be collected, processed, integrated, and disseminated. The ITS complex quickly coordinates road users and performs dispatching functions. ITS often works in covert modes (hidden cables or wireless communication). People use ITS daily in ignorance (e.g., traffic lights or signage with changing messages and information about trains and buses on smartphones). Many are unaware that ITS is a common system. They also fail to consider the wide range of opportunities available from ITS, resulting in an underestimation of the potential to increase profits by further facilitating transportation [23].

To date, several directions adopted for development and research within the framework of the ITS concept have been fully formed [24]. They are the following:

(i) Stationary vehicle control systems designed to inform road users

(ii) Traffic control systems

(iii) Automatic diagnostic systems of transport systems

(iv) Autonomous delivery control systems

(v) Intelligent navigation systems

(vi) Automated payment systems

(vii) Information systems for travelers

(viii) Traffic accident monitoring systems

(ix) Systems for monitoring the condition of road surfaces

(x) Number of systems to support electric vehicles

By summarizing these directions, it is possible to create a complex system to increase the efficiency of the transport system. Such a complex ITS can be achieved by using innovative approaches in the field of sensory networks [25], controllers, and mathematical methods of optimization of information systems [26].

The modern tasks to be solved within the framework of the ITS concept are as follows:

(i) Upgrading road safety to a new level of quality

(ii) Ensuring operational response to road traffic accidents (collisions and natural or man-made disasters)

(iii) Optimization of the capacity of the existing transport infrastructure

(iv) Improving the quality of public transport services

(v) Formation of information infrastructure to support planning systems and development of transport infrastructure

(vi) Management of the technical condition of the existing transport network

(vii) Management of observance of traffic rules

(viii) Automation of electronic payment processes in transport

(ix) Raising the level of awareness of road users

(x) Reducing the damage of transportation to the ecosystem

Several countries have contributed to the development of the ITS line, and the United States (USA) was the first country to study this system. They decided to adopt the dedicated short-range communication technology to address the above tasks [27]. DSRC technology has been developed by the DARPA (Defense Advanced Research Projects Agency) for military purposes. Since 2002, with the financial support of the U.S. Department of Transportation, two consortiums, the Vehicle Safety Communication Consortium and the Vehicle Infrastructure Integration Consortium have been working to adapt to the needs of machine communication. In addition to the United States, research has begun in Europe in the field of machine communications [28]. The Car-to-Car Communication Consortium was created to strengthen research in the field of VANET, which brings together several research groups from Daimler, BMW, Audi, Fiat, Renault, and European universities. The European Committee for Standardization (CEN (ComitéEuropéen de Normalisation)) is currently working on the harmonization of methods of application of the International Standardization Organization and Electrotechnical Commission in the territories of European countries [29].

The Japanese government is also involved in ITS development, with projects focused on improving road safety and streamlining traffic flow optimization and safety [30].

5. Standards and Recommendations in the Field of ITS

In recent years, several technologies that provide automotive communication have begun to emerge. A key aspect of all technologies used at the national, interstate, and international levels is the standardization of these interactive interfaces, data structures, and management systems. As for ITS, the identified areas of standardization receive additional gradation to urban and highway routes depending on the application area. Each of these areas requires its approach to construction and performance parameters.

Regulation of the use of ITS technology in different countries requires consideration of the following several factors:

(i) Peculiarities of radio frequency spectrum propagation

(ii) Features of the existing infrastructure

(iii) Regulatory requirements

However, the pace of development in the automotive industry has required a parallel emergence of active interest in establishing ITS worldwide. With this in mind, several organizations have begun to develop standards in this area. These organizations are shown in Figure 2.

The emergence of standardization in ITS can be considered in 1992 when the International Organization for Standardization (ISO) established 204 technical committees for "intelligence transport systems." The task of this committee is to standardize the management of urban and rural land transport, interaction systems, and information systems [31]. During its development, the committee established 16 working groups to conduct research and standards in the areas listed in Table 2.

In 1992, CEN (European Committee for Standardization (Comite European de Normalisation)) began developing ITS

Figure 2: Organizations developed ITS standards.

Table 2: Composition of the ISO/TC 204 committee.

Working group	1	Architecture
	3	ITS geographic data
	4	Program coordination
	5	Fee and toll collection
	7	General fleet management and commercial/freight
	8	Public transport/emergency
	9	Integrated transport information, management, and control
	10	Traveler information systems
	14	Vehicle/roadway warning and control systems
	16	Communications
	17	Nomadic devices in ITS systems
	18	Cooperative systems

standards in Europe. To this end, the committee established 17 working groups to conduct research and standards in the areas listed in Table 3 [29].

In Europe, in addition to CEN, other members of the European Organization for Standardization (ESO) are also involved. For example, the European Telecommunications Standards Institute (ETSI) [32].

The International Telecommunication Union (ITU) is also an ISO-recognized organization for standardization. The ITU Standardization Organization has teamed up with ISO to develop international standards for ITS. Such a merger will accelerate the production of ITS facilities' quality and affordable communication products to the world market.

The IEEE (Institute of Electrical and Electronics Engineers) has developed a variety of standards applicable to vehicle communications networks. The development of standards for ITS at IEEE-SA has been entrusted to the IEEE 802.11 working group. They developed the IEEE 802.11p standard in 2010, which specifies the data format and structure for the channel and physical layers and the specificity of the priority mechanism for different types of traffic. IEEE

Table 3: Composition of the CEN/TC 278 committee.

Working group	1	Electronic fee collection and access control
	2	Freight and fleet management systems
	3	Public transport
	4	Traffic and traveler information
	5	Traffic control
	6	Parking management
	7	Geographic road data
	8	Road traffic data; organization of WG 3 and WG 4 interactions
	9	Dedicated short-range communication
	10	Man-machine interfaces
	11	Subsystem and intersystem interfaces
	12	Automatic vehicle identification and automatic equipment identification
	13	Architecture and terminology
	14	After theft systems for the recovery of stolen vehicles
	15	Management of the level of the environmental impact of vehicles
	16	Cooperative systems
	17	Ad hoc group urban-ITS

802.11r and IEEE 802.11n standards developed by IEEE are not specialized for vehicle networks but can be useful in their context.

The IEEE 1609 family of standards developed by IEEE is called wireless access in vehicular environments (WAVE). It defines the interaction of machine-to-machine interfaces, architectures, and services for road safety systems. These standards, in combination, form the basis for applications in the transport environment. Examples of applications include road safety applications, payment automation applications, navigation applications, traffic management applications, and more. There are a total of 7 standards in the WAVE family.

(i) *IEEE 1609.0-2013 (Architecture)*. This describes the services required for the interaction of the WAVE architecture and multichannel DSRC/WAVE devices [33].

(ii) *IEEE 1609.1-2006 (Resource Manager)*. This defines the resource manager interfaces and services provided by WAVE applications. This standard defines the structure and format of data flow within WAVE systems. To this end, it defines the format of management failures and the list of possible responses to them, as well as the data format required in the operation of applications to organize interactions between individual components of the system and the query and status message formats [34].

(iii) *IEEE 1609.2a-2017 (Amendment 1)*. This standard defines the security mechanisms for interacting objects in the WAVE system. To do this, the format of security messages, the conditions of exchange, and the options for the system to respond to these messages, depending on the conditions of their receipt, are specified. The standard also specifies the mechanisms for exchanging certificates. In the general case, security mechanisms during the interaction of WAVE objects approach basic principles such as confidentiality, authentication, authorization, and completeness [35].

(iv) *IEEE 1609.3-2016 (WAVE-Networking Services)*. This standard specifies support for transport and network layer services, including routing and secure connection. The standard also shows how applications use WAVE Short Message Protocol and IPv6 as an alternative to the TCP/UDP/IPv6 stack. It also identified management information base (MIB) and logical link control (LLC) [36].

(v) *IEEE 1609.4-2016 (WAVE-Multichannel Operation)*. This standard describes the structure of the improved IEEE 802.11 channel layer for WAVE purposes and tasks. The standard defines how WAVE applications work in a multichannel environment and how to control access to a channel that allows the packet to be distributed to the desired channel at the right time [37].

(vi) *IEEE 1609.11-2010-IEEE Standard for WAVE-Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS)*. The purpose of this standard is to define secure message formats and services for electronic payment systems. In general, payments are shown [38].

(vii) *IEEE 1609.12-2016-IEEE Standard for WAVE-Identifier Allocations*. Identifiers defined in different parts of the IEEE 1609 family of standards are used. The methods of assigning these identifiers and their use are specified in this standard [39].

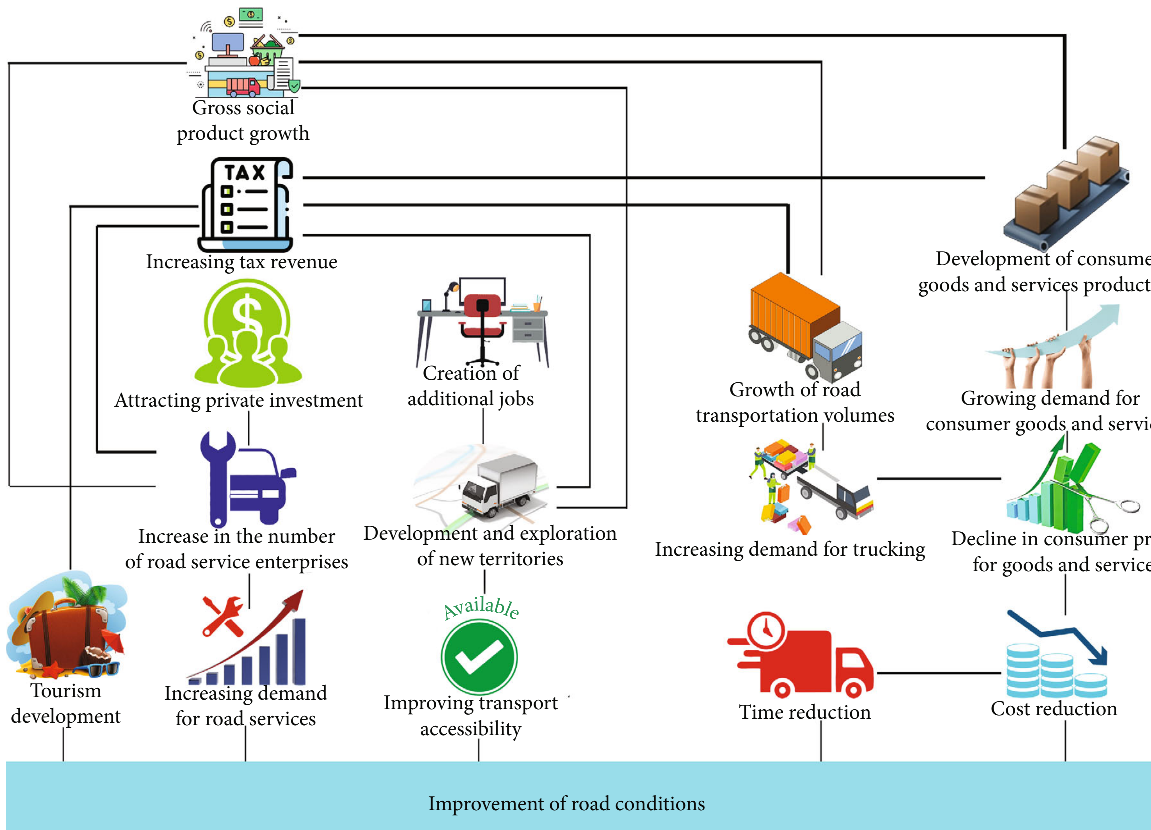


Figure 3: The impact of road infrastructure development on the country's economy.

The Society of Automotive Engineers (SAE) organization has also developed important recommendations for the development of ITS. These are SAE J2365—recommendations on-time accounting for navigation and route detection systems; SAE J2678—recommendations on the availability of navigation and route detection systems during travel; SAE J2945—recommendations on the use of DSRC, etc.

6. Capabilities of ITS

According to the above data, ITS capabilities are fully focused on the intellectualization of transport systems. The application of telematics to the practice of ITS in the world provides an opportunity to solve tasks of economic and social nature transportation, increasing the efficiency of public transport, reducing traffic accidents, improving environmental performance, and ensuring overall transport safety.

The introduction of intelligent transport systems is of a strategic nature, which determines the competitiveness of each country in the world market, and its significant capital requirements mean that it is impossible to achieve without state participation. For example, Market Research Future forecasts that by 2022, the global market size of ITS will reach $42.67 billion for ITS software and devices. In 2019, this figure was more than 30 billion, a growth rate of 10%-12% per year.

Solutions for collecting and analyzing vehicle and road infrastructure data for decision-making are part of the intelligent roads ecosystem.

(i) Traffic flow detectors

(ii) Adaptive (smart) traffic lights

(iii) Means of automatic fixation of violations

(iv) Electronic means of nonstop fare payment

(v) Parking meters

(vi) Connected information boards

(vii) Automated lighting control systems

(viii) Other connected objects (for example, automatic road weather stations, road controllers, etc.)

(ix) GPS/GLONASS systems

A "smart road" element is usually merged on a single platform. Even if used one at a time, they can solve many local problems, for example, traffic lights at intersections change based on the current traffic situation, increasing traffic capacity and reducing traffic jams. Automatic fixation of violations of traffic rules makes drivers more responsible, which, in turn, reduces the likelihood of accidents. Intelligent control of street lighting allows you to save energy.

Figure 3 shows the impact of road infrastructure development on the country's economy. Figure 3 clearly shows an increase in tax revenues, public products, road services, tourism, the availability of transport, demand for freight

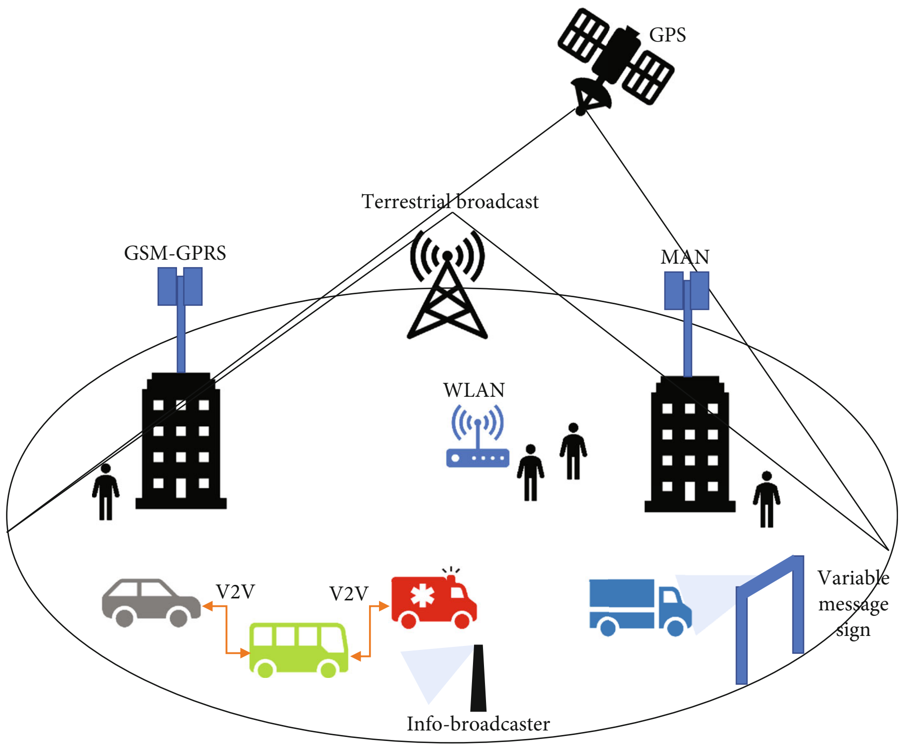


Figure 4: General model of interaction of objects within transport systems described in ETSI EN 302 665.

and passenger transport, the production of consumer goods, prices for related services, and a reduction in cost in time.

7. ITS Architecture

Although much work has been done worldwide to standardize ITS, it is impossible to shape ITS universal architecture. This is because the practical implementation of ITS is closely linked to the goals and objectives of each region. In addition, the technologies, devices, and sensors to be selected also depend on regional factors.

Given these differences, the main direction of ITS development remains the integration of regional subsystems to create a global ITS. One of the main conditions is the high mobility of these control facilities, i.e., vehicles. Given the possibility of interdistrict mobility of vehicles, their implementation on a global scale in the functional capabilities of management should not be left out. This means that the I2V (infrastructure to vehicle) and I2I (infrastructure to infrastructure) interfaces must be implemented in accordance with international standards. As a result, instead of describing the general ITS architecture in modern international standards, models of interaction of individual objects and whole subsystems that meet the requirements of generally accepted technical regulations are given. Figure 4 shows a general model of the interrelationships of objects within transport systems described in ETSI EN 302 665 [40].

Given the specifics of transport systems, the wide range of technologies used, and differences in regional requirements, the following important aspects should be taken into account in the development of interaction standards and the formation of unified architectural approaches to the construction of ITS:

(i) Mobility of the nodes changes in the topology at high dynamics

(ii) Ability to support any type of communication technology

(iii) Ability to support any type of application, including [41–43]

  (a) Designed for ITS

  (b) Applications that use the ITS infrastructure as a transparent tunnel for the transit of their data

  (c) Applications that use ITS only to establish internal communication between connected devices

(iv) The ability to meet the needs of users in terms of bandwidth, availability of a communication channel, connection reliability, security, and cost of communication channels (when using commercial services)

(v) Availability of effective priority mechanisms for different classes of applications

(vi) The potential to support the compatibility of applications and communication technologies, taking into account the differences in the requirements for the functionality of ITS in different regions

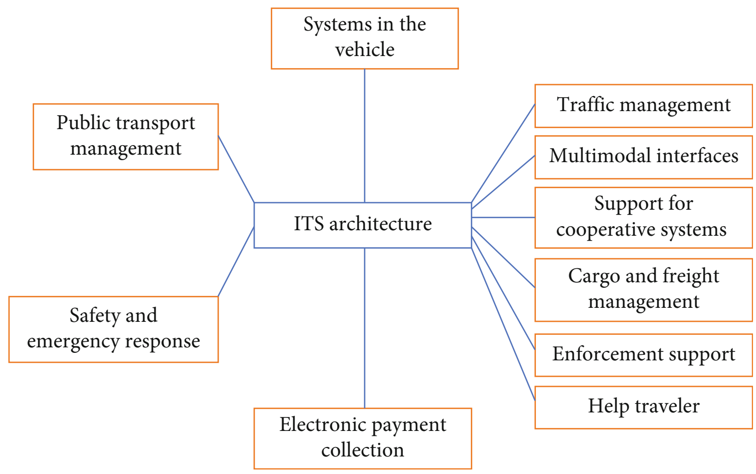


Figure 5: Main functional areas supported by the ITS architecture.

(vii) Support the modular principle of construction with the possibility of increasing the functionality of ITS stations through the installation of additional expansion boards

(viii) Helpdesk profiling

(ix) Global application and expansion

Considering the aspects of implementing the most flexible architecture formed during ITS evolution, the ETSI EN 302 636-3 standard provides the basic principles of building architecture at the subsystem level. It presents a network model of the interaction of ITS stations with each other, as well as ITS stations and external subsystems [44]. At the level of individual ITS stations, standardization was carried out in the form of a generalized reference architecture of nodes represented by interconnected functional blocks with a description of their main purpose [40, 43, 45].

An architecture can contain more than one way of executing a service, and the user can choose the most appropriate functionality to include in their environment. As a result, the architecture is more of a structure from which specific models of integrated ITS may be developed than a model of an integrated ITS.

The main functional areas supported by the ITS architecture are shown in Figure 5.

The advantages of this approach include the unity of terminology and the ability to identify components when merging different architectures.

The concept and structure of ITS should be formed independently of technologies, as shown in Figure 6. In this case, all the requirements of high levels remain unchanged with the development of technology. The information in the system structure enables the ITS industry to design and manufacture equipment and systems that will offer the needed services, each with its unique characteristics but all adhering to the overall system idea and structure's objectives. Thus, the interaction and integration of ITS are ensured.

The structure of the system consists of several blocks. The functional block is necessary for the implementation of ITS services. The communication block establishes the requirements for communications between components. The organization block establishes who owns, manages, and applies each component and other organizational arrangements. The information block contains information about the information used, its attributes, and its relationships.

The methodology for creating an ITS architecture from a system architecture is shown in Figure 7.

The system architecture does not provide for the use of special technologies or specific products because there are two important reasons. First, the ITS architecture designed using the technique will not become outdated because of technological advancements and product development. Second, it allows new technologies to be developed to fulfill specialized functions.

Functional structure (sometimes called logical structure) contains functions, data banks, and terminators. The structure shows how customer requirements are met. An essential component of the functional structure is the scheme of interaction with external objects. It shows the ITS as a single entity and its links to external entities. This diagram makes it possible to define the boundaries of the system, showing what is inside the ITS and what is outside of it in a way that is the responsibility of the ITS developer. In addition, the characteristics of external objects necessary for developing functions within the ITS are established. These external entities are called terminators, which either receive data for the ITS or provide output to end users. The scheme of interaction is also part of the appearance of the system.

The system architecture covers the functional areas of the ITS. Each functional area contains a set of functions connected by data streams.

Data also flows link functions to databases that contain data shared by two or more functions. The functional area is a hierarchical structure. The hierarchy of the structure depends on the following main factors:

(i) Identification of functions required for various purposes, such as car parking, city traffic management, creation of timetables for regular public transport runs, and on-demand public transport management

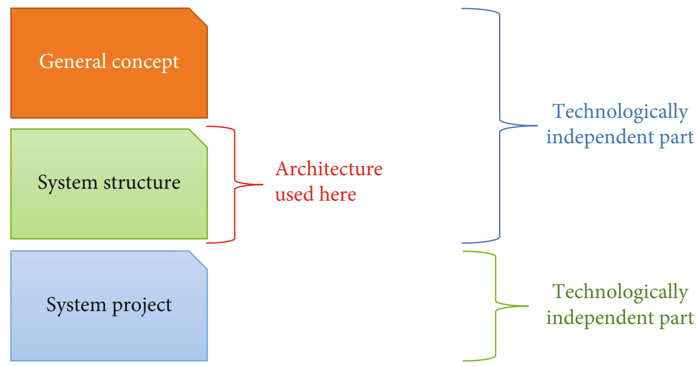


Figure 6: Technological dependencies of the structure and concept of ITS.

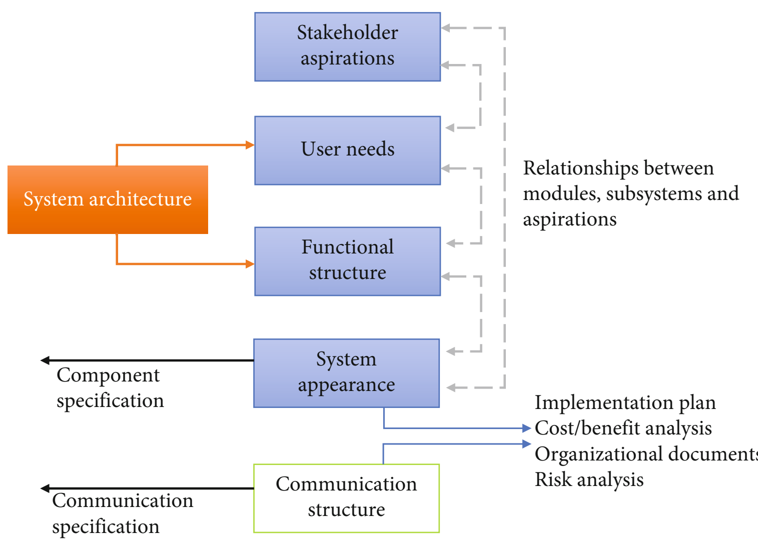


Figure 7: The methodology for creating an ITS architecture.

(ii) Localization of functions in each subsystem of the ITS architecture. For example, road infrastructure equipment in the architecture of one subsystem or a central unit or vehicle in another may be used to perform a certain function. This gives a better chance of finding the optimal system configuration

Another factor that influences the structure hierarchy minimizes data flow between functional areas.

The functional structure allows functions to be localized either within a subsystem or within a module that is part of a subsystem. After that, specifications for subsystems or modules are developed.

The system layout shows where functions and databases should be located physically. Location can be central,

(i) A traffic control center or a freight control center is used by parts of the system to collect and manage the storage and processing of transport data, payment data, freight orders, and/or generation of traffic control measures or fleet management instructions, with or without human intervention

(ii) Peripheral, which elements of the system are used to fix vehicles and pedestrians, collect fees, and/or generate traffic control measures, and/or provide information and commands to drivers and/or pedestrians

(iii) In a vehicle, where parts of the system may be installed at the factory or may be installed later

(iv) In a personal wearable device, where part of the system can be installed so that it can be easily used (and moved) by travelers as part of their personal belongings

(v) In a cargo unit, a part of the system can be installed so that it is an integral part of the cargo transport unit, such as a cargo container, trailer, or body

(vi) Kiosk is the device that may be deployed in a public location to offer passengers restricted and regulated access to specific system features

Analyzing the physical data flows between the ITS and terminators makes it possible to form interfaces for end users.

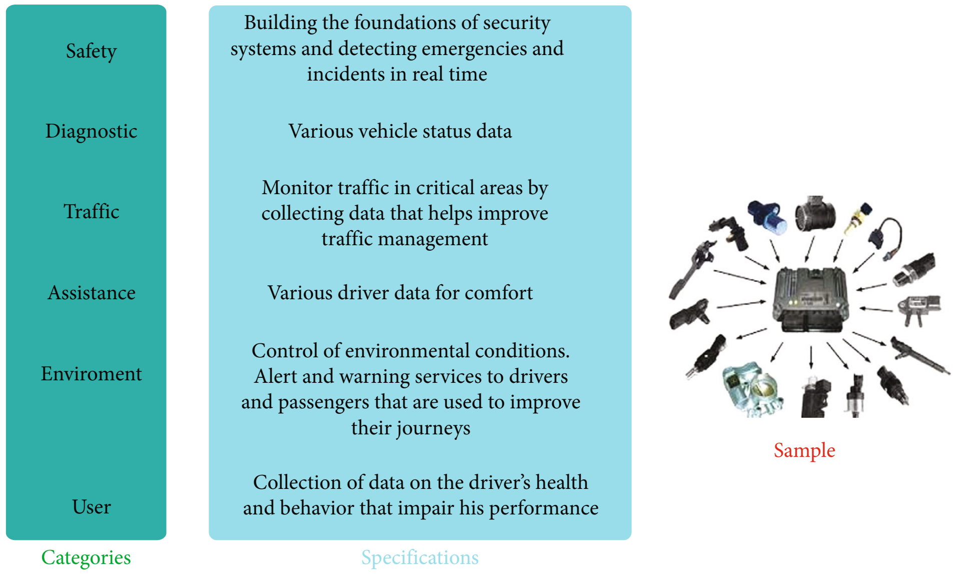


Figure 8: Classification of vehicle sensors.

An important property of the system architecture is the traceability of the entire process. It should be noted that the services contained in most ITS architectures usually cannot be deployed simultaneously for both cost and reliability reasons (i.e., one service may need to be installed before another can be enabled). Thus, when planning the deployment of components and communication lines identified by the ITS architecture, the financial and reliability constraints that the proposed deployment may have must be considered.

System architecture ensures that ITS is systematically deployed, implementation planning, multiple system integration, and interoperability, including cross border.

Intelligent road transport systems are functional devices that collect information, manage traffic flow, and keep road users informed.

Providing the system with the necessary equipment and its complex operation will significantly improve road conditions. In this case, information about the situation on the roads is obtained using various sensor technologies. Therefore, the sensor technologies used in intelligent transport systems are discussed below.

8. Sensor Technology of ITS

ITS uses sensor technologies for data discovery; these technologies are important components used to collect data during communication between vehicles and vehicles with infrastructure [46, 47]. The data collected from these sensors are then transmitted to traffic management systems, which helps solve traffic problems.

Sensor technology is the most common and is currently used in the far-field, such as agriculture, healthcare, and transportation [48]. About 200 sensors can be used in modern smart vehicles [49].

The authors of the two papers classified sensor technologies differently depending on the location of the vehicle [50] and the type of application designed to support the sensor [51]. Using these proposed classifications [52], the author of the paper [51] proposed the classifications in Figure 8 due to the expansion by adding two additional sensor categories to the classification in the paper.

In ITS, it is important to define the types of sensors for developing applications that help solve problems such as parking and traffic congestion, travel time, rising CO_2 concentrations, and warning of traffic accidents. Figure 9 shows the sensors most commonly used in modern cars to improve car performance and increase driving comfort.

8.1. Tire-Pressure Monitoring [53]. This monitoring system helps the driver control the tire pressure. For example, when the air pressure in the tires drops, the driver is sent acoustic, light, and other types of warning signals.

RADAR (radio detection and ranging) and laser perform regular scanning of all sides (side, frontal, and back) of the vehicle, warn the driver in the event of a collision, and ensure that the vehicle brake is activated.

Ultrasonic, proximity, and electromagnetic sensors are mainly used for parking assistance and warning the driver about approaching. For example, an ultrasonic sonar sensor is used to determine how far an object is from a vehicle, proximity detects another vehicle's approach, and an electromagnetic is also mounted on the vehicle's front/rear bumpers to perform a similar function to the above. Sensors of this type are susceptible to external influences (humidity, temperature, etc.).

8.2. Cameras. Cameras are practical in all areas of technological progress, and it is also practical in vehicles. Some vehicles are already used for video surveillance of the driver (eyes, head, fatigue, etc., are observed). In addition, such sensors are very practical for night driving.

8.3. Gyroscope and Accelerometer Sensors. Such sensors have complex algorithms based on their purpose, as they help

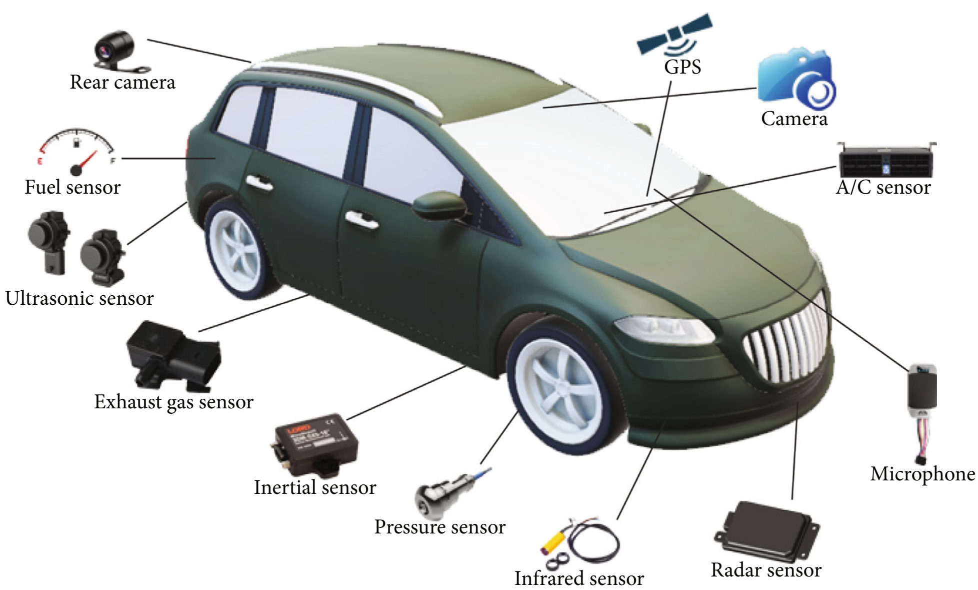


Figure 9: Different types of vehicle sensors.

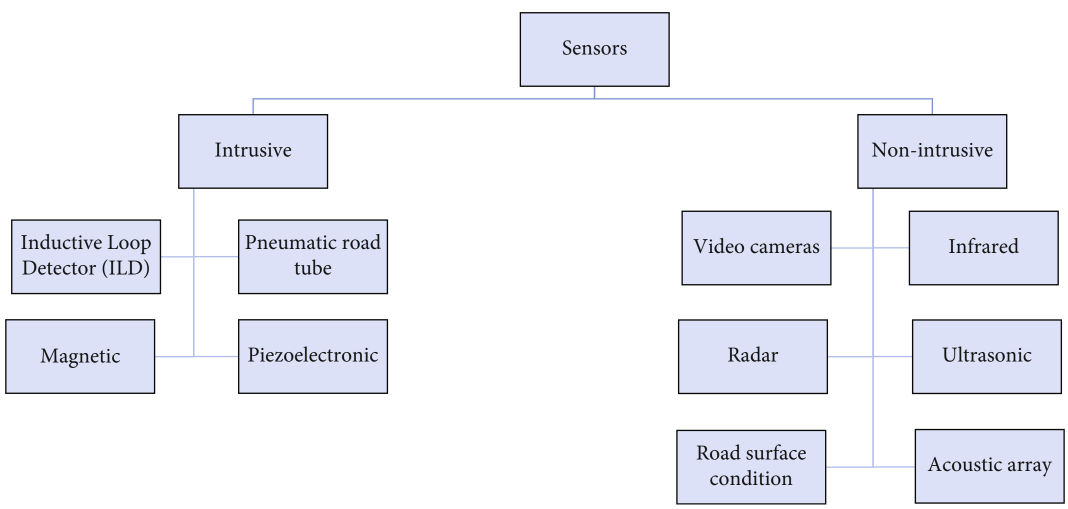


Figure 10: Categories of sensors currently used for traffic control.

determine the car's location, speed, and direction. For accuracy, positions are often combined with GPS (global positioning system).

Radar and speed sensors warns the driver (via a vibrator mounted on the steering wheel or seat) about the potential danger if the vehicle changes direction or is detected to deviate from the road.

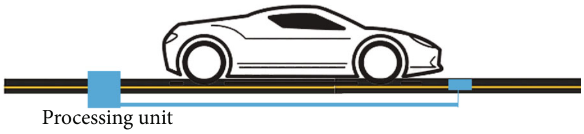
On par with previous sensors, there is such technology as light detection and ranging (LIDAR). This technology helps to see the best 360° obstacle, so it is good in the modern evolution of autonomous cars.

There are many types of sensors used in the vehicles discussed above. While they focus on traffic safety, each has specific and common problems, for example, the lack of generally accepted standards.

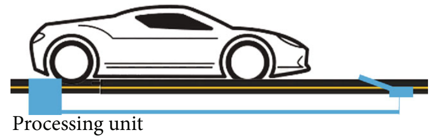
The above sensors help automate processes in the transport infrastructure. In particular, they help improve traffic flow by applying various action algorithms while informing the driver of the relevant data. Here, it is also possible to transmit data on the state of the road to pedestrians. But for the full operation of the entire infrastructure and on the roads themselves, it is necessary to install appropriate sensors.

There are lighting facilities on standard roads, and they have power supplies. Based on this, it is possible to combine various types of sensors that will be aware of the state of the road, passing vehicles, and much more. Such possible sensors are listed in Figure 10 [54].

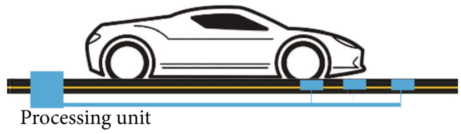
Depending on their location, road sensors can be divided into two categories: intrusive and nonintrusive [55]. Intrusive sensors are mounted on the surface. This category of sensors has such quality as high accuracy, but their maintenance and installation lead to high costs. Intrusive sensors can be broadly divided into passive, magnetic, and sensor



(a) Magnetic sensor

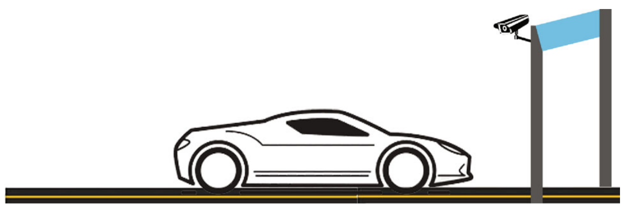


(b) Pneumatic tube sensors



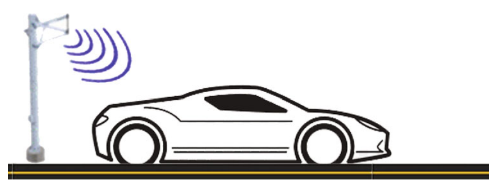
(c) Inductive loops

Figure 11: Categories of sensors currently used for traffic control.



(a) Camera

(b) Laser beam



(c) Radar sensor

Figure 12: Categories of sensors currently used for traffic control.

groups, shown in Figure 11. Wired and wireless environments can retrieve data from intrusive sensors to the control/monitoring block. Sensors in this group are widely used in traffic control systems [56].

Nonintrusive sensors are installed off the road surface, as shown in Figure 12, and detect the passage of vehicles and other parameters. However, they are sensitive to the environment. They are commonly used in developing applications that provide information on queuing at traffic lights, traffic conditions, road weather conditions, and road surface coverage at selected locations. Nonintrusive sensors receive data from sensors, such as intrusive, to the control unit via wired and wireless environments, but unidirectional radio waves mostly drive the sensors themselves. Appropriately here, external physical objects can affect the sensors not working properly.

Most nonintrusive sensors have relatively low installation difficulties, but weather conditions are greatly affected by snow, rain, fog, and more. The road information's accuracy determines the executors' further decisions or actions, while accurate information helps improve conditions. These sensors are visible to traffic managers, which helps them receive timely warning messages such as choosing the right lane and slowing down. Of course, there are problems with the delivery of warning information about the real-time status of the aisle, i.e., the processing of the data collected by the sensors and the speed of their delivery to the traffic controller.

As can be seen from the above, several sensors are used on the roads, of which sensors such as ILD are most commonly used. This is because they can determine the flow, congestion, length, and speed of the road line. The structure of this sensor consists of a long wire wound in the form of a ring and is installed mainly under the road. The principle of operation is as follows when a vehicle passes over it, an electric current is generated in it, and this current is transmitted to the processing unit, and so on to the next corresponding unit for further processing.

Magnetic sensors are installed mainly under the road, performing some duties like ILD. Magnetic sensors are mainly suitable for installation on bridges and are used to measure several parameters, such as traffic speed and availability.

Piezoelectric sensors detect passing vehicles, with the speed of the vehicles set at around 112 km/h. These sensors allow monitoring of up to four lanes of the road.

Video image processor (VIP) system consists of several video cameras, computers, and complex software based on algorithms for interpreting images and converting them into traffic information. Roadside video cameras collect information about traffic conditions by analyzing changes in consecutive shots. The main disadvantage of the VIP system is its reduced ability to work in bad weather conditions.

Radar sensors, sensors of this type, detect all objects in the field of view by scattering low-energy microwave rays.

The following types are available: Doppler's systems, which detect the number, speed, and availability of vehicles by applying a frequency shift in the return of the wave. Accordingly, such sensors generate and receive continuous waves, resulting in high-precision vehicle speeds. In fact, such sensors are very simple to install and are also accurate. An additional plus side is its ability to work around the clock. The main disadvantage is the sensitivity to interference.

Infrared sensors are another popular sensor. It works on the principle of finding radiated energies from the corresponding objects. The principle of operation of sensors can be expressed as follows: event → electrical signal → processing block. Sensors of the type discussed in this paragraph are the passive infrared sensors (PIR) that detect vehicles by reflection or radiation, used to control road lines while collecting data on passing vehicles, availability, and occupancy of the road line. Active infrared light (AIR), laser diodes, or light-emitting diodes (LED) collect information about vehicle flow volume, velocity, availability, classification, and traffic density by calculating reflection time.

Ultrasonic sensors send ultrasounds with a frequency of 25 kHz to 50 kHz from their place of attachment to the object to which it hits and determine the distances by the sound received back. After, as previously stated, the following process occurs: the received sound → electrical signal → processing unit. The disadvantage of such sensors is their sensitivity to influences.

Acoustic sensors work similarly. As part of such sensors, there is a set of microphones. The principle of operation of such sensors is as follows: vehicle approaches/passes in the work area, and the corresponding sound is generated. This sound is amplified by the sensor and sent to the next unit.

Some sensors determine the condition of the road surface. They combine infrared and laser technologies and finally take measurements. The main goal is to implement road repair programs and improve traffic safety. These sensors require constant maintenance to maintain their feature.

Radio-frequency identification (radio-frequency ID (RFID)) sensors are used to identify moving vehicles and collect data. Today, such sensors are widely used in smart parking lots.

Despite installing the above sensors on the road infrastructure, relevant shortcomings related to the information security of the generated data, incorrect compilation, grouping of sensors into one or several different networks, and other similar shortcomings are identified [57]. This will hinder the development of the ITS system, respectively, for automakers, road users, and all others.

The sensors discussed above provide the ability to automate the traffic management system and monitor traffic flow, including real-time traffic monitoring. In addition, modern vehicles are equipped with an average of 100 sensors, which is expected to increase to 200 over time [58]. In addition to generating large amounts of data, these sensors are also important for exchanging environmental information between vehicles. In addition, according to Intel [59], shortly, a midrange car (i.e., a personal vehicle used daily) will generate 4 GB of surrounding data every eight hours while driving. This is an additional 650 Mb per day for the average vehicle driver, and shortly, this average figure could increase to 1.5 GB.

These sensors uniquely generate various information, which is optimized by transmitting the generated information to the appropriate addresses and performing some operations on them. Of course, communication technologies are used to transmit data from sensors. Below are the communication technologies used in smart transportation systems.

9. ITS Communication Technologies

The creation of ITS is aimed at ensuring the exchange of information at all levels of interaction between the objects that make it up. The functionality of the services provided fully and completely determines the content of this information exchange.

The heterogeneous structure of these services places different demands on the resources needed for their normal operation. In addition, these requirements may vary depending on the level of interaction. As a result, the solution to the problem of integrated delivery of information services within the ITS is achieved through the convergence of many modern wireless technologies.

The whole set of communication technologies used in ITS today can be divided into two categories, as shown in Figure 13. The first category includes, in particular, special technologies designed or adapted specifically for the goals and objectives of ITS. These include DSRC, WAVE, and CALM. The second category also combines well-known wireless technologies serving within the ITS to expand the coverage area of this category of technologies, as well as to ensure the required width and stability of the provided data transmission channels.

Dedicated short-range communications technology (DSRC) operates at a frequency of 5.9 GHz, where a frequency band of 75 MHz (5.85 GHz-5.925 GHz) is allocated for its functions [27]. It is specially adapted for information exchange between transport infrastructure and moving vehicles. The transition from DSRC to Wi-Fi technology began in 2004, based on the IEEE 802.11a protocol, which focuses on reducing the additional cost of performing communication processes. However, it failed to prove itself well in practice because it failed to provide reliable communication during the high-speed movement of communication objects. As a result, after some changes in the channel and physical layers of the IEEE 802.11a protocol, the IEEE 802.11p protocol emerged, which served as the basis for transmitting information over the radio channel for DSRC technology [33]. It should be noted here that DSRC's move to the IEEE 802.11p protocol has led to its frequent use of the WAVE wireless protocol.

These improvements, implemented within the IEEE working groups, aim to minimize communication time. This allowed communication facilities to exchange information at vehicle speeds up to 200 km/h. The SAE J2735 [60] standard defines the structure and content of this information exchange.

In the automotive environment, the wireless connection system (WAVE) deals with the issues of interoperability and

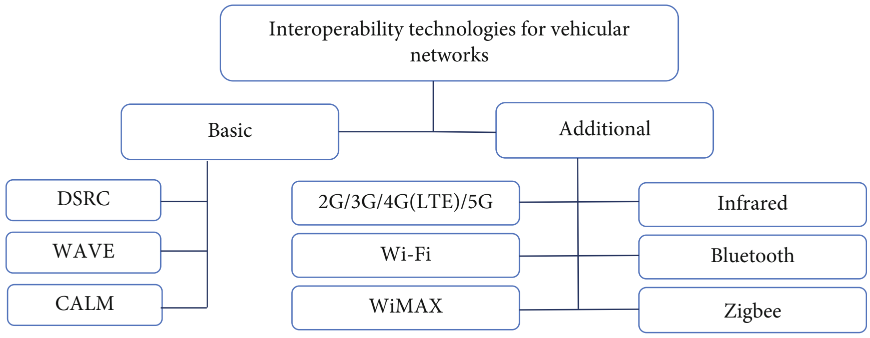


FIGURE 13: ITS communication technologies.

continuity of services provided by ITS. In addition to the IEEE 802.11p protocol, WAVE includes the IEEE 1609 family of protocols, which define the top layers of this system [33].

Combining these protocols allows for receiving information about car traffic and accidents in real time. In addition, depending on the requirements, the transmission of information can be done in conjunction with security tools. The functionality implemented within WAVE, in general, has made it possible to use it as a core for systems called DSRC/WAVE systems [61]. The generalized architecture of WAVE is shown in Figure 14 [62].

A series of standards for ground access for mobile objects (communication access for land mobiles (CALM)) has been developed by the ISO/TC 204/16 working group. CALM is a tool focused on the requirements of applications to create an ITS communication platform [63]. To do this, CALM provides a set of protocols, technologies, and communication interfaces, the selection of which can be made dynamically depending on the needs of applications or channel quality [64–67]. The flexible architecture of CALM allows for interoperability based on IPv6 and without using IP at all. In addition to the interconnection standards between moving objects in CALM, there are also types of ISO 29281, ISO 15628, and ISO 24102 rapid interconnection standards. Similar technologies are also used to implement various types of electronic payment systems [62].

In addition to the interoperability methods for ITS, third-party systems communication protocols and general-purpose technologies are designed to expand the system's core capabilities. Thus, payment for information from the car's internal sensors and connecting drivers' and passengers' devices to a single onboard network can be made using well-known and proven technologies such as Bluetooth and ZigBee. The priority of ZigBee technology, where the data transfer rate does not exceed 250 kbit/s, is to interrogate onboard system sensors and combine the collected diagnostic data into internal memory, which service centers can use to analyze the vehicle's technical condition [30].

Bluetooth technology includes ZigBee technology and short-range communication technologies. But in the fifth generation of this technology, data transfer speeds can reach up to 2 Mbit/s. Given the widespread use of Bluetooth as a core package of wireless technology for data exchange between devices, its inclusion in the list of ITS communication technologies is a clear step towards expanding system capabilities. This technology allows road users to share small amounts of data easily. Several businesses currently manufacture traffic controllers with Bluetooth interfaces. By identifying devices with Bluetooth interfaces enabled, many features can be developed, such as a safe and convenient pedestrian crossing routine, crossing routes in congested road areas, and simplifying situation assessment.

Suppose the transmission speed and bandwidth of the channel are insufficient to perform certain services. High-speed mobile data transmission technologies such as Wi-Fi or 2G, 3G, and 4G (LTE) are used. This technology allows the creation of communication channels at speeds of several hundred Mbit/s. The fifth-generation (5G) of mobile communications currently being developed and tested is designed to increase data transfer speeds and energy efficiency, as well as add the ability to connect directly from device-to-device (D2D) [68]. All this allows for closer interaction of the Internet of Things (IoT) components, to which can be added ITS objects. However, it should be noted that some features of mobile systems differ from ITS, i.e., ITS resources are openly used in the interaction of devices of network service users.

While maintaining the provided bandwidth, the ITS coverage area can be expanded through WiMAX (Worldwide Interoperability for Microwave Access) technology. This technology's unique features allow for eliminating interruptions in the provision of ITS services for vehicles moving along the roads between settlements.

In addition to wireless technologies, ITS integrates computing resources distributed across network nodes, storage systems, and diagnostic components expressed in sensors, such interdependence of software and hardware solutions and communication technologies which allow moving ITS work to a qualitatively new level.

10. The Role of VANET in the ITS Structure

VANET (vehicular ad hoc network) is a self-organizing vehicle network that is equipped with special communication devices. It is one of the most important components of the ITS. The purpose of this network in vehicles is very wide, and its first purpose is the safety of road users. The task of this network is to timely notify drivers about the

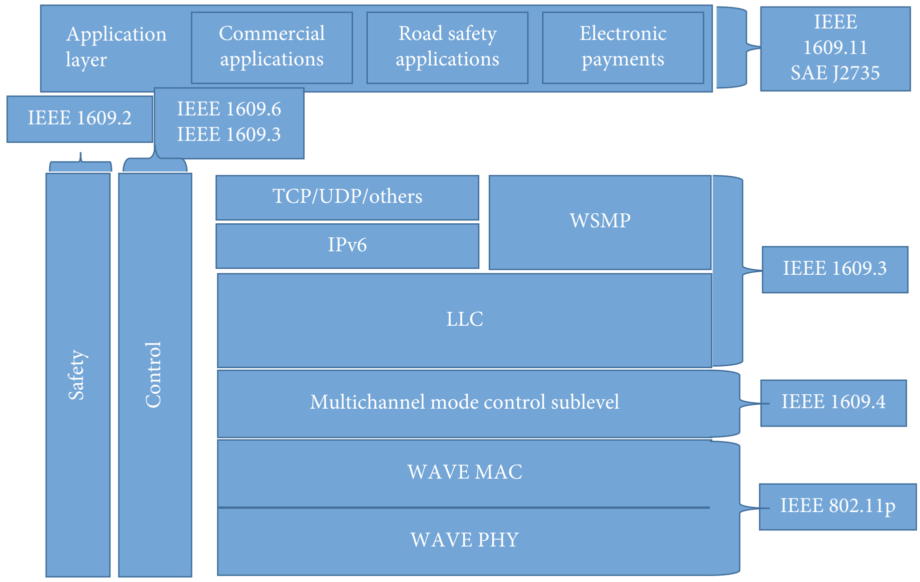


Figure 14: WAVE protocols stack.

traffic situation, traffic congestion, distribution of vehicle traffic, and others [68, 69].

This type of network plays the most important role in drawing up the ITS concept. It forms a highly dynamic specialized transport network and helps transmit data coming from sensors installed on the road and naturally on the transport itself. When dealing with the VANET network, you need to understand that this network is an important beginning of ITS scaling. This type of network is very flexible as it can interact with itself or other types of networks. As a rule, such complexities and the needs of a given network are costly but do not affect the importance of this network in ITS [70].

The VANET network has several special features, such as high node density, high vehicle speed, inconsistent network structure, and grouping by region. All these network features impose special requirements on the order and parameters of work. Thus, the most important key requirement is minimizing delays in transmitting information and maintaining the network connectivity of applications, i.e., traffic safety applications, traffic management, and the like. Such requirements imply the need to use the WAVE-specific wireless technologies listed in the section on interconnection technologies [71].

The fact that VANET has an important role in the structure of the ITS is undeniable since cars play a big role in the transport system, and this type of network is focused on the characteristics of the behavior of these cars. At the same time, the VANET network also focuses on various families of standards, all of which determine the interconnectedness of the ITS with this network.

VANET has placed the following elements in its main architecture: RSU (Roadside Unit) infrastructure base stations with special telecommunication modules OBU (On-Board Unit), and similar communication interfaces installed in vehicles. OBU is an integrated module attached to the vehicle board, which includes various information, transceiver, and processing devices. For the interaction of VANET modules, communication interfaces are included in the unchanged composition. These interfaces refer to software and hardware modules. Depending on the direction of data transmission between objects, the following types of interfaces are distinguished [61, 72, 73]:

(i) *Vehicle-to-Vehicle (V2V)*. This type of interaction is carried out between vehicles. This type of interaction is necessary since there may not always be intermediate base stations on the roads. Accordingly, in this type of interaction, short messages are used to exchange information about situations

(ii) *Vehicle-to-Infrastructure (V2I)*. This type of interaction primarily aims to reduce the congestion of wireless interfaces. This type is well suited for organizing data collection and sending data to a management center, followed by traffic regulation

(iii) *Infrastructure-to-Infrastructure (I2I)*. RSUs are in interconnection. Here, data can be transmitted by various communication channels, such as wired or wireless. Accordingly, here, the data rate can be very high

(iv) *Vehicle-to-X (V2X)*. This type of connection is universal; here, you can create as far as possible with any interaction interface

(v) *Vehicle-to-Broadband Cloud (V2B)*. This type of interface connection is used to interact with cloud services. Broadband technologies are used in this interaction

(vi) *Vehicular to Home (V2H)*. This type of connection provides interconnection with IoT objects that are installed in the smart home. Here, there are ample opportunities for expanding the range of functions,

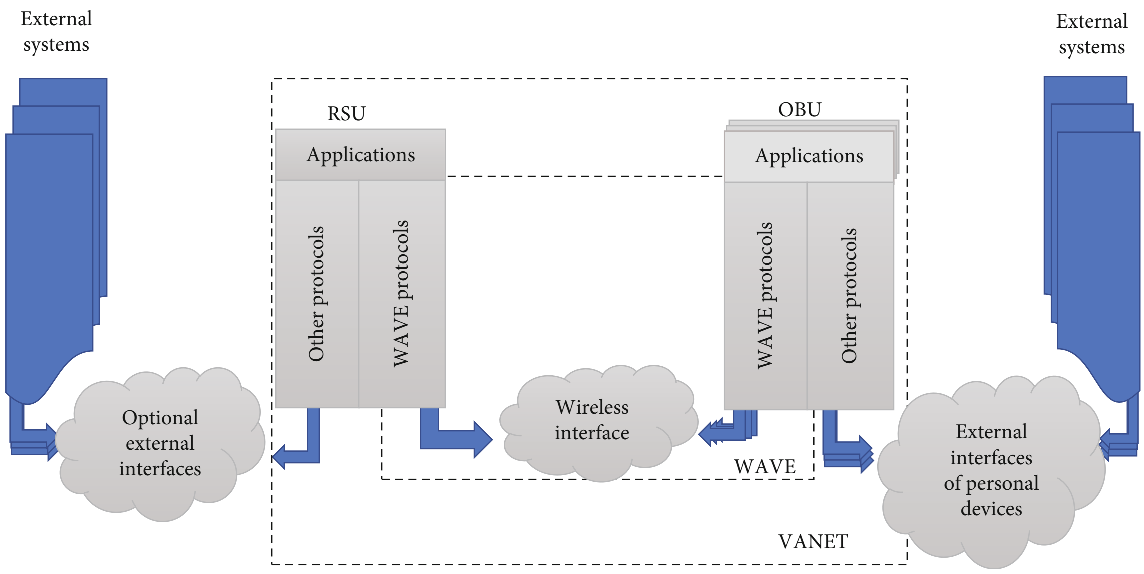


Figure 15: VANET communication model.

for example, vehicle diagnostics without leaving home, data transfer from home to vehicles, and much more

11. Methods of Information Exchange in VANET

VANET has several methods for transferring data. They are closely related to the capabilities of the protocol stack shown in Figure 13. The efficiency of commercial services is mainly achieved through the use of TCP/UDP+Ipv6 packages from well-known wired networks. This data transfer stack provides for such a special protocol as WAVE Short Message Protocol (WSMP) to ensure road safety, collect statistical data on the state of road traffic, and provide contactless or wireless electronic payment services [33].

The WSMP protocol was designed to reduce latency in a WAVE environment. It also becomes possible to control the physical layer, signal strength functions, and channel number when transmitting data. The interaction model and technologies, taking into account the VANET content, are shown in Figure 15.

When using the WSMP protocol, the data is downloaded using a specially structured WSM (WAVE Short Message) message. This WSMP protocol has some shortcomings despite its efficient use of channel resources. Messages can only be transmitted in areas where the signal can be processed. If it is needed to start processing data, IPv6 will start working with routing tools. Another problem is the regulation of broadcasting over a network. If there is no limit to the retransmission of messages, it will lead to a storm of widespread dissemination. In this case, when messages are generated at each new step, the number of messages increases many times and leads to the complete depletion of the channel resource. To overcome this problem, several studies have been linked in the turn decade [74–81]. However, in the case of moving to check the dynamics of changes in the exposure composition, it is not possible to use a wide gravity mode. This conclusion is drawn because it helps solidify how the data is broken.

Based on the composition of automotive networks, they can have a single-tier and hierarchical structure. The use of RSU in a network mode in a single-stage structure is not intended. Information is transmitted on a point-to-point (P2P) or point-to-point (P2MP) basis for broadband broadcasting. The P2MP mode corresponds to a star network topology. The involvement of RSU in exchanging information allows the creation of a “cluster tree” topology. In this case, the data exchange between OBUs and interaction with other ITS services is carried out through the nearest RSU. An interconnected RSU allows the organization the exchange information between clusters. This simplifies the wireless communication channel and significantly increases network connectivity. The network technology capabilities provided by VANET components are shown in Figure 16.

The IEEE 802.11p protocol is a necessary set of specifications that enable communication between wireless nodes to be fast and dynamic. Let us compare this protocol with its predecessor, IEEE 802.11. We can identify the following, the time interval required for identification, authentication, and connection to an access point for data exchange is shorter than that specified in the IEEE 802.11 standard. The protocol redefines the operating mechanisms of the physical and channel surfaces to achieve such performance.

11.1. Physical Layer. The physical layer of the IEEE 802.11p protocol is a modification of the physical layer parameters of the 802.11a standard shown in Table 4. The changes aim to adapt the protocol to the requirements of high mobility of subscribers, frequently changing network topology, and automotive applications.

VANET uses OFDM (orthogonal frequency division multiplexing) modulation to organize the data exchange process by dividing the total network width of 75 MHz into

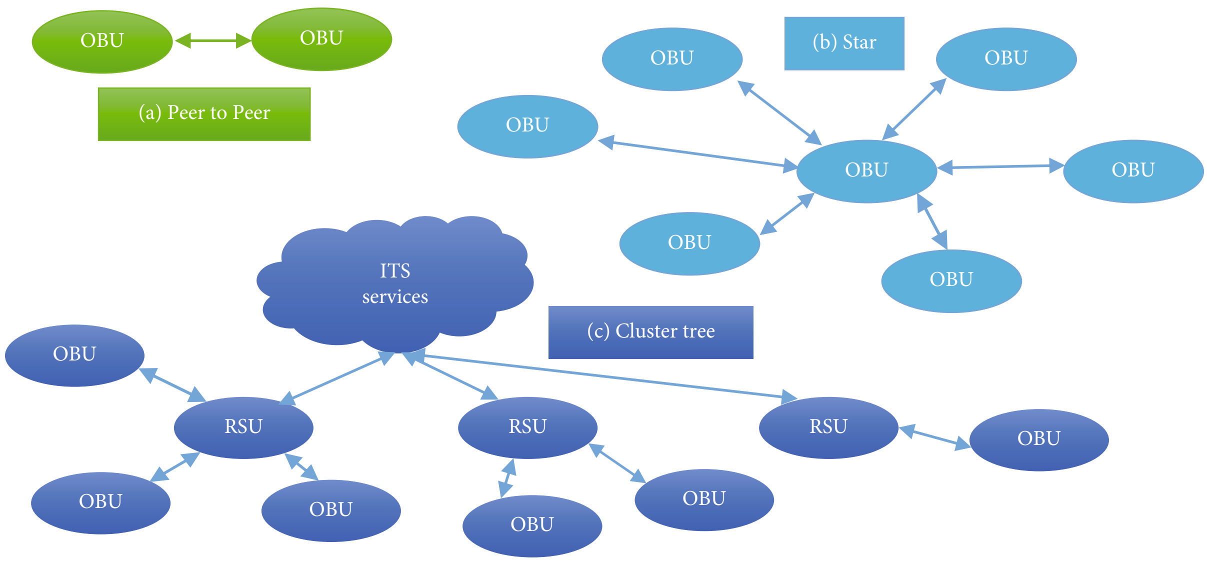


Figure 16: VANET topologies.

Table 4: IEEE 802.11a and IEEE 802.11p.

Parameter	IEEE802.11a	IEEE802.11p
Bit rate (Mbit/s)	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27
Type of modulation	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Code speed	1/2, 2/3, 3/4	1/2, 2/3, 3/4
Number of subcarriers	52	52
Symbol duration	4 ms	8 ms
Guard interval	0.8 ms	1.6 ms
FFT period	3.2 ms	6.4 ms
Preamble duration	16 ms	32 ms
Subcarrier interval	0.3125 MHz	0.15625 MHz

small channels of 10 MHz. This provides a data transfer rate of 3 Mbit/s to 27 Mbit/s. Combining adjacent subchannels into a single channel with a width of 20 MHz allows for achieving a data transfer rate of 54 Mbit/s, respectively [24].

The frequency range of 5.85 GHz-5.925 GHz in the United States is allocated for VANET functions. It envisages the formation of a single control channel (SCC) and up to six service channels (SCH) with numbers 172-176 and 180-182. The frequency spectrum distribution into lower channels is shown in Figure 17. CCH is designed for messages related to network management. SCH channels are used to deliver application traffic and other traffic (user IP traffic) [82].

In Europe, VANET functions have a frequency range of 5.85 GHz-5.925 GHz, as in the United States, but the distribution method to the lower channels differs from that in the United States. The distribution of the lower channels in Europe is shown in Figure 18. In addition, in Europe, access technology, which is implemented in conjunction with the lower two levels of LLC (Logical Link Control), is defined as a separate element of architecture following EN 302 665 and is called ITS-G5 [39]. This element of the architecture is responsible for creating nodes in the ad hoc order without interconnection. According to EN 302 663 v1.2.1, all allocated frequency bands are divided into three subbands for ITS-G5 functions [24]:

(i) ITS-G5A (5,875 GHz-5,905 GHz) contains three channels, each with a frequency of 10 MHz, and is designed by ITS-G5 devices to perform emergency services

(ii) ITS-G5B (5,855 GHz-5,975 GHz) includes two channels, each with a frequency of 10 MHz, and is designed to perform a variety of application services

(iii) ITS-G5D (5,905 GHz-5,925 GHz) includes two channels, each with a frequency of 10 MHz, and is designed to implement the services of new ITS applications

In addition to frequency division, WAVE also provides time allocation of resources for each channel. Resources for this are provided in "time slots"-time intervals during which stations can exchange information. As a result, in accordance with the IEEE 1609.3 (2016) standard, the use of radio channels by VANET nodes, as shown in Figure 19 is possible in one of three modes.

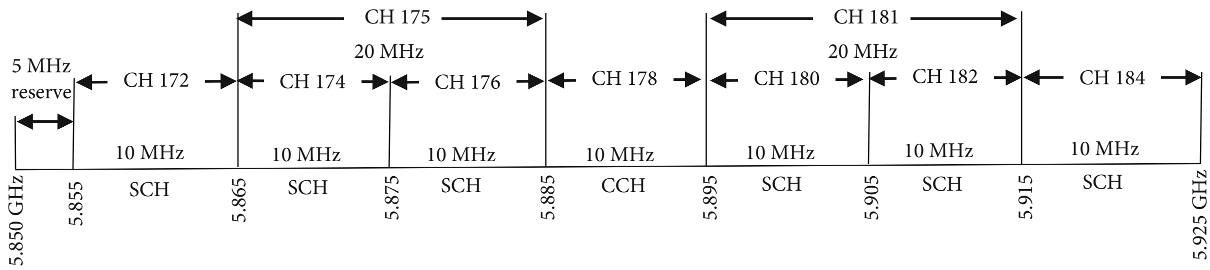


Figure 17: Frequency spectrum distribution in the United States.

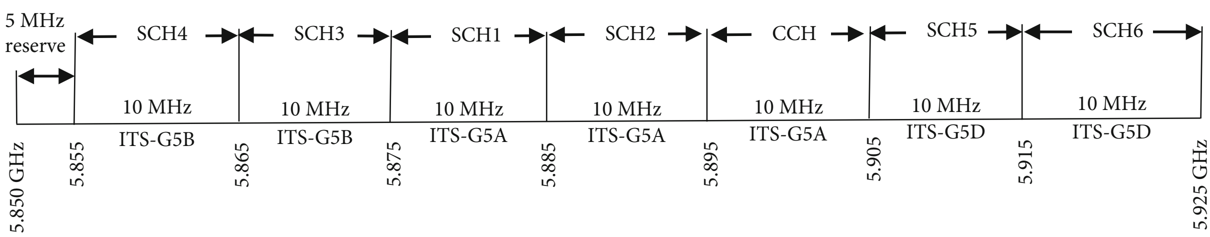


Figure 18: Frequency spectrum distribution in Europe.

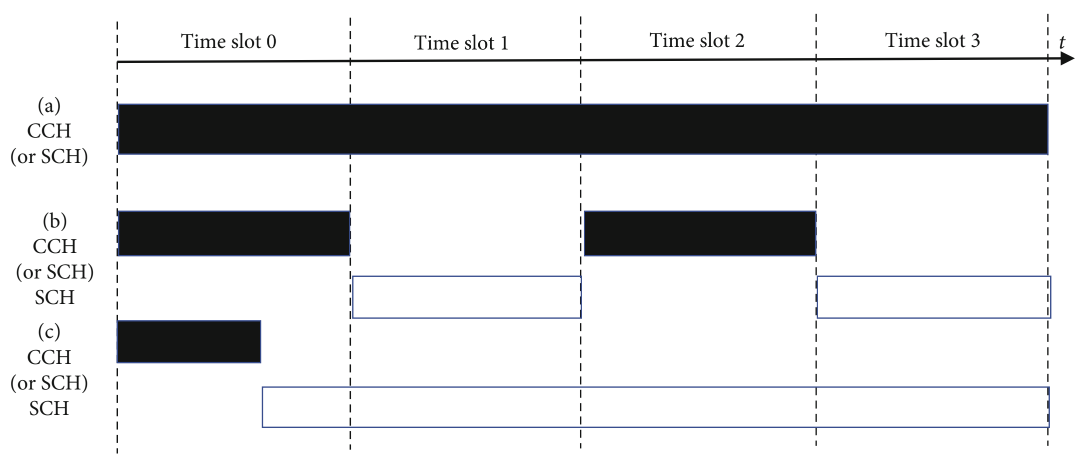


Figure 19: Allocation of time resources across subchannels.

(i) Continuous mode when the nodes communicate continuously only through the CCH or only through the SCH (Figure 19(a))

(ii) Alternate mode involves two channels, CCH and SCH, or alternate interaction through SCH and another SCH. Channel change occurs in each new timeline (Figure 19(b))

(iii) Emergency mode allows switching from one channel to another without waiting for the current timeline to expire at the request of higher-level applications (Figure 19(c)).

11.2. Channel Layer. Channel layer algorithms are designed to determine when a node can perform a transmission based on the channel's current state and the transmission queue's state. This function aims to increase the probability of successful reception of the transmitted data and minimize interference with other transmitted data. MAC algorithms for automotive networks are defined by the IEEE 802.11p protocol [83].

The IEEE 802.11p protocol, adapted for the V2V-type interconnection task, has inherited many features from its predecessor, the IEEE 802.11a protocol. The most important of these is the channel distribution mechanism. The IEEE 802.11p standard provides for three types of input coordination at the MAC level: "distributed coordination function (DCF)," "point coordination function (PCF)," and "hybrid coordination function (HCF)."

DCF distributed mode is the basic technology of ad hoc interaction without a central coordinating device.

DCF technology is called EDCA (enhanced distributed channel access) in conjunction with QoS (quality of service) management mechanisms added for VANET networks, partly derived from the IEEE 802.11e protocol [37, 83]. EDCA technology is based on "carrier-sense multiple access with collision avoidance (CSMA/CA)" technology. The channel's status is listened to during AIFS (arbitration

Table 5: Entry categories for EDCA.

Category numbers	User category	Access category	Traffic type
1	Background (BK)	AC_BK	Background
2	Spare (-)	AC_BK	Background
0	Best effort (BE)	AC_BE	Best effort
3	Excellent effort (EF)	AC_BE	Best effort
4	Controlled load	AC_VI	Video
5	Video (VI)	AC_VI	Video
6	Voice (VO)	AC_VO	Voice
7	Network control (NC)	AC_VO	Voice

Table 6: OFDM PHY parameters used in IEEE 802.11p.

Parameter	Value
aSlotTime	13 ms
ASIFSTime	32 ms
aCWmin	15 ms
aCWmax	1023 ms

Table 7: Methods for calculating the delay interval value.

Access category	Cwmin	Cwmax	AIFSN
AC_BK	aCWmin	aCWmax	9
AC_BE	aCWmin	aCWmax	6
AC_VI	(aCWmin + 1)/2 – 1	aCWmin	3
AC_VO	(aCWmin + 1)/4 – 1	(aCWmin + 1)/2 – 1	2

Table 8: AIFS and CW calculation values for IEEE 802.11p.

Access category	Cwmin	Cwmax	AIFS (ms)
AC_VO	3	7	58
AC_VI	7	15	71
AC_BE	15	1023	110
AC_BK	15	1023	149

interframe space) before the frame transfer to the MAC layer is performed. In an unsuccessful transfer attempt, a CW (contention window) delay interval is set for the node, during which time the node does not attempt to perform the transfer.

At the channel level, QoS involves grading all transmitted data into eight categories of Ups (user priorities) and four categories of access categories of users, as shown in Table 5. Category 0 is the lowest, and category seven is the highest.

The final value of AIFS is calculated according to the following formula for each entry category:

$$\mathrm{AIFS[AC]} = \mathrm{AIFSN[N]} \times \mathrm{aSlotTime} + \mathrm{ASIFSTime}, \quad (1)$$

where aSlotTime is the duration of a single timeline.

In ASIFSTime, the duration of the SIFS (short interframe space) range is defined in PHY, and it is given in Table 6.

The CW delay interval value calculated for each failed transmission attempt iteration depends on an input category similar to AIFS [AC]. The methods for calculating its value are given in Table 7.

Using the values given in Table 6, Formula (1), and the formulas in Table 7, the final values of AIFS and CW for the various Acs of the IEEE 802.11p protocol can be obtained (Table 8).

For a more detailed understanding of the data transfer preparation process, they are taking into account the operation of the EDCA mechanism, the architecture of the IEEE 802.11p standard network transmission node section shown in Figure 18. This architecture describes channel routing, priority queuing processing, and retransmission channel management operations. As shown in Figure 20, the control of the SCH and CCH channels in the transmission path structure is performed separately.

The WAVE environment provides the ability to transmit three types of information:

(i) *Management Frame*. Designed to transmit synchronization information and implement the services provided, which can be transmitted on any channel

(ii) *Data frame*

(iii) *Control Frame*. IEEE implements the functionality described in 802.11 without any extensions

In the architecture mentioned above, it can also be seen that both WSMP and IPv6 are supported for data transmission from higher levels. But WSM can be transmitted on any of the desired channels, while IPv6 data can only be transmitted on the SCH channel.

12. Network Parameters of ITS

As in other interconnected systems, intelligent transport system objects have specific network parameters in the organization of interconnection.

12.1. Quality of Service. This parameter determines the quality of data transmission to each other during the interaction of ITS objects. This option also includes package quality and successful delivery.

The packet delivery ratio is a parameter that determines the number of packets successfully transmitted by nodes. Objects in the ITS system can also act as nodes, so it is advisable to consider this parameter as one of the important parameters.

12.2. E2E (End-to-End Delay). This parameter determines the time delay in the path from the data source to the destination. This parameter is important in traffic safety applications.

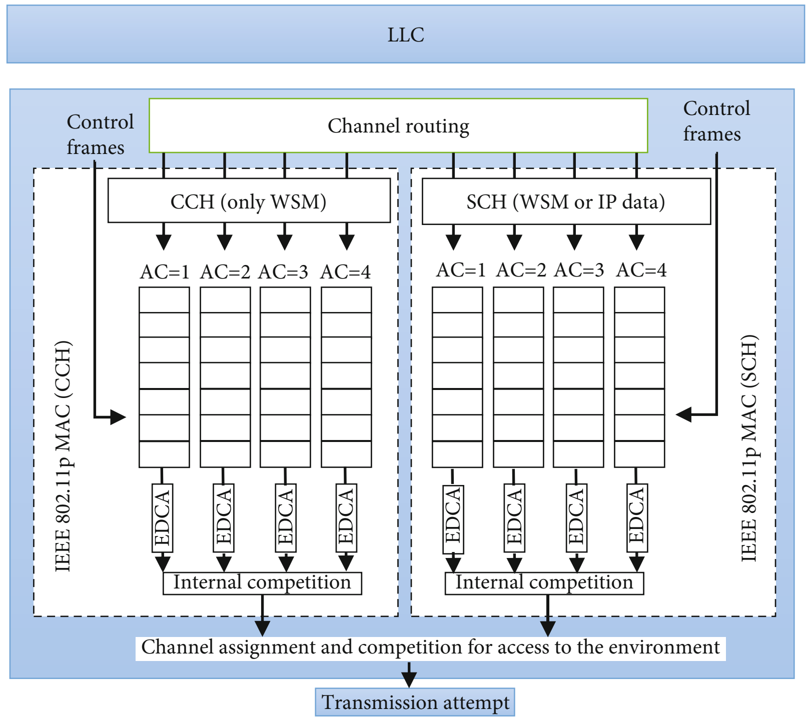


FIGURE 20: The transmitting side architecture of the VANET node.

Jitter is a parameter that measures the presence of a delay in packet transmission (i.e., if the packet arrives from the source at 10 ms, some packets are later than this time (15 ms) plus delay time (5 ms) is called jitter). Such situations in the interaction process of ITS objects affect the quality of applications.

Latency is a parameter that measures the time it takes for a packet bit to reach an adjacent node between subsequent passes.

12.3. Overhead in Routing. This parameter is evaluated when using the routing protocol. It detects the addition of additional service messages to the flow of data packets with limited bandwidth, and it is called the additional cost of routing.

12.4. Routing Hop Count. This parameter determines the number of available hops on the selected route path. The smaller the number of such passes, the shorter the route. This option is useful in the optimal selection of routes from the vehicle to the roadside block and then through the base stations to the central servers.

Network congestion is a load on a node that results in the transmission of signals by two or more ITS communication devices. This parameter is very important in exchanging messages about events, and it is advisable to prevent it.

The percentage of packet loss is a parameter that determines the number of packets lost when transferring a data packet from the source to the destination. The loss of the emergency data package among road users can lead to unpleasant situations, given that this parameter is also important.

Throughput is a parameter that determines the maximum number of bits that can pass through a communication channel in a given time interval. It is an important parameter in determining the compatibility of a device, communication channel, and related technologies, taking into account the exact amount of data generated in the ITS system.

In addition to these parameters, several other parameters help ensure optimal interaction between ITS objects.

13. ITS Applications

ITS applications are classified according to their main purpose [45, 71, 83].

(i) *Safety Applications*. These are applications designed to improve the safety of vehicles on the roads

(ii) *Traffic Flow Management Applications*. Applications for the formation of info-communication structures to optimize traffic flows for various purposes

(iii) *Applications of General Importance*. Applications designed to provide commercial or entertainment services

Also, data security problems in applications of an intelligent transport system have a significant role. The following researchers have considered such problems [84–86].

The main goal of applications of general importance is improving passenger conditions [87, 88]. Passengers in vehicles that travel long distances on the roads may be interested in using automotive networks in similar areas. It consists of providing a lot of different information. Through this method, it is possible to provide passengers with various information, such as ads, entertainment content, weather reports, nearby restaurants, and hotels. For drivers, additional information on the location of nearby parking lots and gas stations can be provided. Passengers have access to office work, receiving/sending e-mails, and Internet access when the vehicle is connected to the infrastructure network [73, 88, 89].

Applications of the above type should not interfere with high-priority applications such as security. In this context, traffic priority and using separate physical channels is the appropriate solution, as described in the channel layer section.

One of the main tasks assigned to ITS in an urban setting is the intelligent management of these traffic flows. To do this, data on the current status of traffic flows will be collected through the installation of base stations, sensors, surveillance cameras, and other detection devices pertaining to road sections. The collected data will be analyzed in the coordination centers, and based on the analysis results, control measures will be taken to coordinate traffic flows. Such control actions include: changing the operation of the traffic light to limit the speed and screens that provide various types of warning information [90].

Another way to influence traffic flow is to directly send information about congestion and road conditions to the OBU. This information can be displayed on the onboard navigation aids and encourage drivers to choose alternative routes.

14. Smart Parking System in ITS

The smart parking system, which is part of the intelligent transportation system, will have a very large volume in the structure of smart cities. This paper suggests a smart parking system as shown in Figure 21. One of the positive aspects of this smart car park is the flexibility of the research into the existing infrastructure, i.e., the work being done on the infrastructure on which the project is being carried out.

This smart parking system envisages the development of processes for the location of parking sensors, vehicle identification [91], vehicle registration, the connection of payment systems, databases, control algorithms, websites, mobile applications, and other intelligent systems.

Before applying the above smart parking system, it is necessary to calculate characteristics that apply to each parking space separately. Parking spaces can be located at the marketplace, organizations, or along the road. Consider the example of parking spaces of an educational institution.

First, it is necessary to determine the required number of parking spaces while determining it is necessary to take into account the specialization (i.e., the delay of visitors), the uniformity of visits, etc.

Car parking can be seen as a system that satisfies the demand for parking vehicles and has limited capacity to meet this demand. Therefore, we can consider the parking process as a queuing system, where one car parking space is a service channel, and cars arriving at the parking lot will be the incoming flow of requirements. Considering parking as a queuing system, one can quantify its functioning.

The Erlang formula can express the marginal probabilities of all parking states depending on the number of parking spaces, the intensity of demand, and the duration of parking. The probability that k channels are occupied by service.

$$P_n = \frac{(\lambda/\mu)^k (1/k!)}{\sum_{k=0}^{n} (1/k!)(\lambda/\mu)^k}, \tag{2}$$

where l is the density of the flow of applications (intensity of demand for parking); n - is the number of channels (the number of parking spaces); k is the number of free channels; $m = 1/t$ is the service flow intensity; t is the average service time for a requirement in the system (parking time).

Most often, instead of the ratio l/m, the concept of the reduced intensity of the flow of requests r is used, which is the number of requests arriving for the average service time of one request.

$$p = \frac{\lambda}{\mu}. \tag{3}$$

A special case of Formula (2) is the probability P_0 that all serving channels are free.

$$P_0 = \frac{1}{\sum_{k=0}^{n} \left(p^k/k!\right)}. \tag{4}$$

Knowing the probabilities, P_0, P_1, P_2, P_n, we can find the characteristics of the efficiency of the parking operation—the absolute throughput A, the average number of cars in the parking lot, and the probability of denial-of-service P_{den}.

Probability of refusing to service a newly received request (lack of free parking space).

$$P_{den} = P_0 \frac{p^n}{n!}. \tag{5}$$

Parking capacity,

$$A = \lambda(1 - P_{den}). \tag{6}$$

The average number of free parking spaces (number of free channels),

$$N'_0 = \sum_{k=0}^{n-1} (n-k) P_k = \sum_{k=0}^{n-1} \frac{a^k (n-k)}{k!} P_0. \tag{7}$$

The average number of cars in the parking lot (number of canals serviced),

$$N' = p(1 - P_{den}). \tag{8}$$

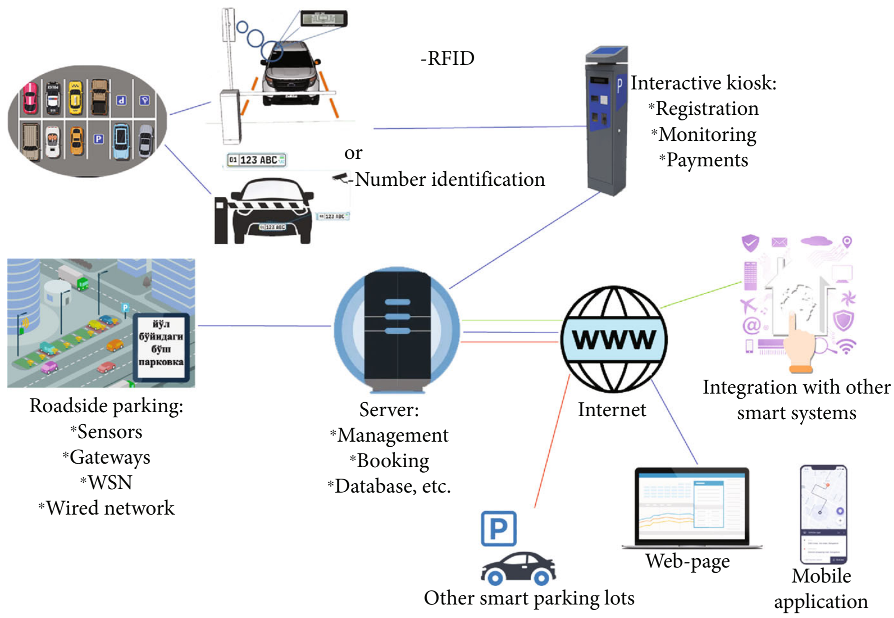


Figure 21: Smart parking system.

Parking usage rate,

$$K_n = \frac{N'}{n}. \tag{9}$$

The use of dependencies Formulas (2)–(9) for assessing the functioning of parking lots with a capacity of more than 100 parking spaces is associated with a problem in calculating factorials of large numbers. In this case, the parking space can be divided into m segments operating in parallel. Let us assume that the demand for parking d is evenly distributed between the segments,

$$\lambda_m = \frac{d}{m}. \tag{10}$$

Formulas (3)–(5) will take the following form:

$$p_m = \frac{\lambda_m}{\mu}, \qquad P_0 = \frac{1}{\sum_{k=0}^{n} \left(p_m^k / k!\right)}. \tag{11}$$

Using the probability addition theorem, we determine the probability of denial of service as follows:

$$P_{\text{den}} = \prod_m P_0^m \frac{p_m^{\;k}}{k!}, \tag{12}$$

or with an equal probability of denial of service in all segments,

$$P_{\text{den}} = \left(P_0 \frac{p^k}{k!}\right)^m. \tag{13}$$

Carrying out a parking performance assessment requires knowing the intensity of car arrivals at the parking lot and the average parking duration. Suppose the intensity of arrival is the input of the systems of the system under study and is determined by various external factors. In that case, the average duration of parking is an internal characteristic of the queuing system. To assess this parameter, field surveys were carried out in the parking lot of the educational institution.

Let us consider the use of this method to analyze the functioning of parking at an educational institution with a capacity of 500 parking spaces and the intensity of demand for parking 600 cars/hour. Let us divide the parking space into $m = 5$ segments with a capacity of $n = 100$ parking spaces. The calculation is given in the tabular form.

Input parameters are shown in Table 9.

As you can see, a parking lot with a capacity of 500 cars satisfies the demand for parking with an intensity of 600 cars/h, while the probability of a lack of free parking space is less than 1%, and the available parking spaces are used by 92.7%.

After these calculations, parking design options are considered. The design of the parking lot depends primarily on the circumstance, taking into account the climate, the surface occupied by the parking lot, and similar paramount factors. Climatic conditions affect the decisions of the master plan, shaping the choice of constructive solutions and materials. For this reason, it is necessary to analyze the climate of the area.

In the second stage, you need to determine what kind of parking will be, i.e., open, indoor, underground, and multilevel. After determining the type of parking, respectively, it is necessary to consider the composition of the earthen soil for compliance.

After that, the parking layout is determined, i.e., parking spaces, lighting, sensors, entrance to/exit from the parking lot, and places for people with disabilities (they are located closer to the sidewalks and closer to the building itself).

Table 9: Calculation.

Parameters	Calculation formula	Value
Demand for parking for a separate λ_m segment	(10)	120
Reduced demand flow rate p_m	(11)	107,18
Probability that all serving channels are free P_0^m	(12)	$1,22.10^{-46}$
Probability of denial of service in all segments of the parking P_{den}	(14)	0,0044
Average number of free parking spaces	(7)	31,48
Average number of cars in the parking lot	(8)	463,68
Parking usage rate	(9)	0,927

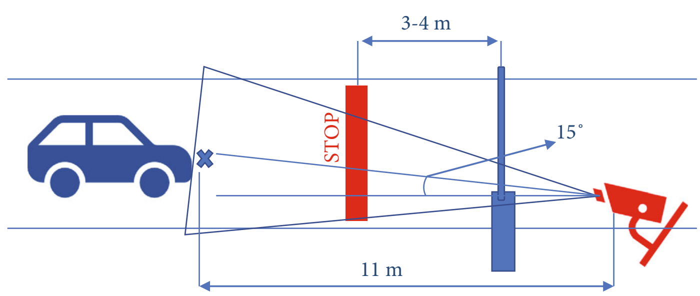


Figure 22: The classic version of the camera installation.

Barriers are usually installed at parking entrances, and various technologies are used to identify the vehicle. They mainly use RFID or video surveillance with recognition, which you can use in combination. In the case of using RFID, everything will be managed through a transponder and a reader with further information systems [91]. The second case is more interesting; through it, you can get a lot of information about the vehicle, and the functionality will be wider. But it will be necessary to take into account all possible characteristics, camera resolution, its installation location, and additional illumination of the visible range.

When recognizing vehicles through video cameras, the camera resolution must be at least 200 pix to ensure image quality; such requirements are met by HD cameras 1280 × 720. Here, you need to take into account that more highly accurate images are good, but there may be delays in computing processes when processing such data.

The classic version of the camera installation: height, 3 m; distance to the control zone, 11 meters. In this case, the angle in the vertical plane is 15 degrees, and in the horizontal up to 10 degrees, with a passage width of 4 meters (Figure 22).

Number plate recognition applications for smart parking are guided by algorithms and use specific image processing methods.

Consider various methods and algorithms for recognizing license plates. The license plate identification process can be divided into preliminary license plate search (localization) and character recognition.

There are several ways to presearch a number.

(i) Analysis of boundaries and shapes, contour analysis

(ii) Analysis of part of the boundaries

(iii) Histogram analysis of regions

(iv) Statistical analysis, classifiers

(v) Finding and highlighting the part containing the number using wavelet transforms

Number plate recognition applications for smart parking are guided by algorithms and use certain image processing methods.

Methods and ways of character recognition.

(i) Tesser act OCR

(ii) K-nearest

(iii) Correlation method

(iv) Recognition of skeletal patterns

(v) Adaptive recognition

(vi) Neural networks

There are also libraries for license plate recognition. Let us consider some of them.

Opos project Implemented in C# to recognize the license plate, and the port of the computer vision library OpenCV in C# is used. To recognize the characters of the number, a wrapper in C# is used over the Cunei from the OCR library-Puma.NET. The disadvantage of the implementation lies in the difficulty of using the library in real-time systems because the image is first saved to disk and then transferred to Puma.NET.

JavaANPR project released in Java. The advantage of this library is that it is suitable for any OS. All algorithms are written in Java without the use of native libraries, and this greatly simplifies its use. This library can be used in real-time systems, as it has a fairly high recognition rate: 0.2 sec-0.8 sec. For one license plate.

Along with systems already available on the market and ready-made methods and algorithms for recognizing license plates, there is the possibility of implementing a recognition system in a graphical programming environment National Instruments (NI) LabView. In addition to universal development tools for computer control and measurement systems, such as the LabVIEW graphical programming environment and the PXI modular hardware platform, National Instruments also offers a wide range of specialized software libraries and hardware modules. One of the specialized hardware and software technologies of National Instruments is the machine vision platform (NI Vision), which consists of (IMAQ) image acquisition (capture) technology and software technology for its processing and analysis. With vehicle recognition, there are many implementation options. After completing the above, the necessary parking sensors are installed and connected to one network via wired or wireless communication lines [89]. Here, you can also use the cameras to determine the parking place.

All installed systems are generally integrated into one large system on a server computer. You can install the database on the server computer corresponding to the application, etc.

Having done all the above work and their further testing, you can implement them in other parking lots with further integration into a single, smart parking system. They can be connected to smart city systems.

In its comprehensive implementation, ITS is designed to improve overall traffic by detecting the state of safety, efficiency, and service through real-time data transmission using advanced electronics, communications, computers, control, sensing, and detection technologies in all modes of transport.

15. Conclusion

The paper analyzes the evolution of ITS from the birth of an idea to modern high-tech implementations. As part of this analysis, the development stages and standardization processes were generally considered, and a smart parking system was proposed with some of its calculations. It was noted that the complex structure of ITS includes a wide range of modern technologies and wireless protocols designed to implement a global infrastructure for providing various information services. The analysis revealed several problems with information security in ITS communications, the limited bandwidth of the data transmission channel in-vehicle sensors, the complexity of routing processes during data transmission, and others. And also, during the implementation of the smart parking system, difficulties were revealed in identifying the vehicle through cameras; difficulties can be with polluting vehicles in which the number plate is not visible. Smart parking requires a lot of calculations, from planning to completion of all processes.

16. Future Work

The scope of further work on ITS is unknown, and the following research is expected to be conducted in this area in the future:

(i) *Traffic Safety*. Delivery of first aid kits using drones in a traffic accident. This situation is very useful in traffic congestion

(ii) *Parking*. Develop an integrated parking system in an integrated city, around organizations, and elsewhere. This system is designed in a specific direction around the world but is not designed for general cities and organizations

(iii) *Freight*. Several works have been carried out in transportation, but these processes have not been fully considered. This line has a very wide range of possibilities, and a lot of work is currently being done on vehicle monitoring, in addition to which robotization processes are expected to be carried out

(iv) *Information Security*. Multiple network devices are used to send the information generated in the vehicles to the appropriate addresses, and there is no guarantee that the information will change on these intermediate devices. Appropriate technologies such as blockchain technology should be used to ensure that this information is delivered to the address in its entirety and unchanged

(v) *Information Processing*. It is expected that the amount of information in vehicles will increase in the future. It is expected that the processing, analysis, and subsequent forecasting of this large data will be done through cloud systems, as the processing of such information at a single point will require very high costs

(vi) *Ecology*. CO_2 emissions from vehicles harm the environment. For this reason, it is necessary to install appropriate sensors in smart urban areas and manage traffic flows accordingly

(vii) *Others*

Considering the above information in subsequent models and algorithms of intelligent transport systems is advisable.

Data Availability

The data is available in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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