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Overview of Road Traffic Management Solutions based on IoT and AI

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Abstract

In recent decades the number of vehicles on the world's roads has continued to increase. However, road capacity does not develop at the same rate, which generates a considerably increased congestion rate. To minimize this difficult problem, the researchers opted for intelligent and efficient use of existing infrastructure through adaptive traffic management. The various recent proposed approaches have been based on new technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Big Data. In this paper a global vision on various road traffic management solutions proposed in the literature is introduced, a classification and an evaluation of these road traffic management solutions are proposed. In particular, we start by presenting routing mechanisms, then solutions that are based on the use of traffic lights, then approaches that aim to manage network traffic. We discuss these solutions thereafter. Finally, we present new directions for future research on urban road traffic management.

Keywords: Smart cities; Traffic management; Intelligent Transportation Systems; Artificial intelligence; Internet of Things

1. Introduction

Despite all the research carried out in the field of traffic management, road congestion remains a real headache for managers and road users alike. The main reason behind this is the continuous and faster increase in the number of

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vehicles than the traffic infrastructure available to support it. This problem is difficult to manage, it evolves in time and space. Thus, road traffic congestion has many social, ecological, economic, and health consequences, such as degradation in the quality of life of road users, significant loss of time, decrease of competitiveness and productivity, and an increase in pollution. To combat this phenomenon, researchers are trying to take advantage of emerging technologies such as the IoT, AI, Big Data, and other new technologies to create and develop new intelligent solutions for Intelligent Transportation Systems (ITS). ITS allow the integration of a broad set of systems including communication, detection, traffic control, and information dissemination in order to solve transport problems and improve the overall efficiency of transport systems [1].

This article presents an overview of the different existing solutions for urban road traffic management and an evaluation of these solutions. The remaining part of this article is organized as follows: In section 2, road traffic management solutions are presented. Section 3 exposes some network traffic management solutions. Section 4 discusses the different traffic management solutions presented. Section 5 concludes the article.

2. Road Traffic Management

2.1. Traffic Guidance

In road networks, drivers have the choice between several routes that lead to their destination. Intelligent use of traffic data could help optimize this choice, thus reduce the destructive impact of congestion [2]. To do so, several mechanisms of routing that rely on AI, Big Data, and IoT have been developed and described in the literature.

A method of urban traffic route guidance with high adaptive learning capability in different traffic scenarios is proposed in [3]. This method is based on the concept of AI, in particular on Multi-Agent Reinforcement Learning, in order to minimize road congestion. It consists of a combination of two algorithms, the first algorithm is MQ (Modular Q-learning) which is based on the special and temporal characteristics of several different traffic scenarios to accurately estimate the cost of the road trip. The second algorithm is the trajectory A*Rejection which uses the road network congestion index to determine the effective path of each vehicle for efficient traffic.

Praveen et al. [4] relied on the Big Data concept in the development of a smart urban Traffic Management System (Travel Distance). The traffic data is taken from the New York Traffic Map. On the basis of these data, traffic issues are predicted using the ARIMA method (Auto Regressive Integrated Moving Average) which compares and analyses the data from the previous year. After that comes the phase of finding the shortest path from a source point to a destination point using enhanced Dijkstra's algorithm which opts for the least weight found in the different paths of the graph. Then an enhanced time forecasting algorithm is used to measure and improve the performance of the proposed traffic management system. Finally, the detection of traffic in Map analysis is charted. Apache Spark and R-tool are used for real-time analysis on the Apache Hadoop platform and for statistical computation and map analysis respectively.

Amer et al. [5] present a centralized dynamic multi-objective optimization algorithm that takes advantage of Vehicular Ad-Hoc Networks (VANET), which is the main part of the Internet of Vehicles (IoV) which in turn is a part of IoT technologies, to overcome the traffic challenges. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication systems have been assumed to use Central Access Messages (CAMs) or beacon messages. Road Side Units (RSU) try to have an overview of their assigned segments of the road network and then exchange their information between them in order to have an overview of the state of the entire road network. The proposed approach in this article combines the Simulated Annealing (SA) method and the VIkOR method to provide the new Centralized SA-VIKOR (CSA-VIKOR). It makes it possible to select the most optimal paths, to direct vehicles to their destinations, based on a cost function of the VIKOR type. The CSA-VIKOR algorithm is based on the MADM (Multi Attribute Decision Making) method so that it directs vehicles to the least congested paths based on several attributes, namely the traffic lights on the roads, vehicle density, average traffic speed, length, and width of roads.

2.2. Traffic Light Control

Researchers have proposed various approaches for minimizing congestion at intersections based on three ways of collecting traffic data, namely, Wireless Sensor Networks (WSN), VANET, and Cameras and image processing [6]. A distribuTed and AdaPtive IntersectiOns Control Algorithm (TAPIOCA) is proposed in [7]. Its supporting infrastructure is a hierarchical architecture of a distributed WSN. It consists of a first layer of sensors called Before Light which is responsible for the continuous collection of vehicle arrivals at the intersection, and a second layer called After Light. This layer have less load since it only works during the green light, it is then responsible for collecting the departures of vehicles from the intersection, the aggregation of the data collected for each movement, the execution of the decision-making process, and finally transmitting the calculation result of the traffic light phases to the various sensors of the network and to the Traffic Light Controller. In this architecture, sensors select particular sensors for each task, and the Control Center can always act on the entire network. This algorithm is characterized by the use of a conflict matrix that brings together all possible conflicting movements and directs the creation of phases, allowing it to be flexible and adaptable to any intersection configuration. In [8] Faye et al. generalized the TAPIOCA solution on several intersections by synchronizing neighboring intersections and creating green waves.

Rapelli et al. [9] present V3TL, V2V-based Virtual Traffic Light, a dynamic distributed solution that creates a cyclical planning process for vehicles approaching the intersection to decrease waiting time. It minimize the number of actions required to clear the intersection and the number of stop and go of each vehicle to reduce emissions. The vehicles interact with each other based on V2V communication. The data collection is done in four steps, S1: vehicles near the intersection exchange Basic Safety Messages. S2: leader election and Leader String compilation. S3: direction Leaders exchange Leader Strings, then merge them into the intersection String. And finally S4: each DL computes the scheduling solution that is called Solution Dataset and broadcasts it with the Leader String.

Maram et al. [10] have developed an algorithm based on traffic data collected in real time using VANET technology to dynamically and efficiently plan the phases of each cycle of Intelligent Traffic Lights (ITL). The traffic flows, which are not in conflict, are scheduled to pass the intersection at the same phase. The algorithm takes into consideration several parameters, including MAXGREEN, the maximum time that can reach the green phase in order to ensure a reasonable sharing of the intersection between all the traffic flows, and BESTGREEN, the time of the green phase which is defined separately for each traffic flow based on the traffic distribution in real time. The presence of one or more emergency vehicles is reported at the intersection using vehicular communication. The planning algorithm checks whether the emergency vehicle can pass the intersection in the current green phase by calculating the distance between them, in which case the MAXGREEN time may be exceeded. If several emergency vehicles arrive at the same time, they will cross the intersection according to their priority.

In [11] two algorithms are proposed, firstly an ITL Controlling algorithm (ITLC) for the intelligent planning of traffic light phases of an isolated intersection. This algorithm is based on the characteristics calculated in real time for the traffic flow of the same platoon, following a protocol called ECODE. The latter is a periodic exchange of data between neighboring vehicles of each Ready Area, a virtual square, using VANET, then their communication to the relevant traffic light. The second algorithm is for Arterial Traffic Light control. It is an adaptation of the ITLC algorithm for open network scenarios. It takes into account the scheduling reports of neighboring traffic lights located on the arterial street. These reports are delivered using vehicles traveling along arterial flows, the closer the intersection is, the more it is taken into account in phase planning. This algorithm ensure green waves on the artery.

Image processing techniques, and M2x IoT (server) platform are used in [12] to monitor and control traffic density. The Raspberry Pi (Rpi) is used as an intermediary between the server and the traffic lights. The system uses a USB camera to capture the images of the traffic in real time, then Rpi compares these images with a reference image using the Background Subtraction method. Then, the density information is sent to the server which, using a desktop Java application, monitors and controls the traffic lights remotely. However, to cover the entire intersection, one camera should be used for each direction, further, the detection of emergency vehicles is not taken into account. These latter challenges are overcome in [13] which represents a new method of traffic control at intersections. This approach is based on fuzzy logic, it uses a smart camera for each lane of the intersection to properly monitor, assess traffic in real time, detect, track special vehicles and help prioritize emergencies. A distributed flexible adaptive and phaseless city traffic control algorithm is presented it uses information from smart cameras and traffic rules to effectively control traffic lights. For the image processing part, BS operation, an algorithm based on the Region based Convolution Neural Network, and OpenCV (Open Computer Vision) were used. Dubey et al. [14] also used a microcontroller, image processing algorithms like Haar cascade and BS to control traffic at the main intersections of roads. First, the acquisition and processing of images are done respectively by cameras and a microcontroller placed at intersections. Based on the traffic density the Timer is controlled. Third, all traffic data is sent to the server and made available to users through an application. This application offers a routing service to help road users choose the least congested routes. Traffic data can be used for security purposes.

3. Network Traffic Management

In smart cities, effective crowd management is essential for a rich, safe, and intelligent service experience [15]. In [16] a comprehensive urban road traffic management framework for assessing, reducing cybersecurity issues, and facilitating effective traffic management and cybersecurity is presented. This complete framework is composed of four strictly linked stages. Stage1: regulation of street intersection signals to optimize urban traffic management. Each intersection tries to improve its signalling parameters to decrease the delay of local traffic. Stage2: assessment of cybersecurity risks in traffic management. Stage3: Decrease cybersecurity risks by deploying countermeasures against the various problems that can occur during urban traffic management. Stage4: Apply the complete framework to the large-scale urban transport system. In order to increase traffic efficiency and safety, the use of hierarchical control and management based on Multi Agent System should be done rather than a centralized system.

Zhao et al. proposed in [15] a Deep Reinforcement Learning-based Smart (DRLS) routing algorithm to solve the Successful Service Access Rate Maximization (SSARM) problem in smart cities in order to improve the utilization of network infrastructures and avoid network congestion when massive crowds move around smart cities. The semi-supervised DRL method of learning merges the perceptual capacity of deep learning with the decision capacity of reinforcement learning in order to acquire the maximum cumulative rewards.

In [17] Ning et al. present a three-layer Vehicular Fog Computing (VFC) architecture to solve the problem of distributed traffic management in real time. VFC is a combination of fog computing and the vehicular network. First there is Cloud layer, it monitors and controls the entire city remotely in a centralized way. It is composed of a Traffic Management Server and a Trusted Third Authority. Second there is Cloudlet layer. Each Region of the city has its Cloudlet which is responsible for receiving data reported by vehicles and processing them before passing them to Cloud layer. This layer requires the use of gateway, routers, access points and even RSU may also exist. Finally, the fog layer which consists of vehicles and devices in the wireless communication range of RSU. This layer is based on vehicles close to RSU to form fog nodes for VFC. Some traffic data can be used for vehicle-level network decision making and others can be transferred to RSU. These latter decide where this data should be processed by Cloudlet or fog nodes. These operations make it possible to alleviate the network loads and therefore to minimize the response time.

4. Discussion

As highlighted in the previous sections, researchers are interested in different problems of traffic management in order to minimize road congestion. Various performance measures have been taken into consideration, as mentioned in Table 1, in order to measure the performance of the suggested solutions.

For route guidance methods and traffic light control methods there are Average Travel Time (ATT), Average Fuel Consumption (AFC), Average CO2 emission, Average Waiting Time (AWT), and Average Travel Distance (ATD). The routing mechanisms aim to quickly offer better alternative routes for drivers in order to create a balance between the benefit of the individual and group. Thus, an almost global balance of the traffic load on the whole road network can take place, and therefore part of the congestion problems is solved. Optimizing ITL control means optimizing the real-time traffic statistics collection module and optimizing the intelligent traffic control module to achieve the best green and red intervals.

Regarding the real-time traffic data collection module, three data sources are frequently used, namely, WSN, VANET, and Camera-based image processing techniques. For WSN, they were used extensively for the collection of traffic data, and they have proven to be precise and effective in detecting movements and events [6]. This method requires expensive installations (in case of inductive loop sensors…) or involves a large amount of material (in case of infrared sensors…). On the other hand, VANET technology does not rely on a pre-existing infrastructure, it establishes an extensive network of connected vehicles communicating with each other by considering each vehicle as a wireless transmitter, receiver, and router node. For VANET also, several solutions have been proposed in the literature and they have been judged as effective solutions for the alleviation of traffic congestion in environments where the penetration rate of Connected and Automated Vehicles reaches 100% [18], which is not the case in the real world now and to reach it in the future, there is still a very long way to go. Finally, by relying on various techniques of image processing, the camera becomes a good traffic data source. Video surveillance at intersections allows to force people to obey the Highway Code and to detect and classify vehicles. It also has the advantages of a simpler and more economical installation, maintenance, and distribution since cameras can be mounted on extant traffic signal poles [6]. Regarding the intelligent traffic control module, various approaches have been used to solve the congestion problem, among them there is game theory approach, Multi Agent System, AI skills such as fuzzy logic, Neural Network, Deep Learning, Reinforcement Learning, and Deep Reinforcement Learning [19].

Regardless of the method followed in solving the congestion problem, each solution has its own specific characteristics. From Table 1 it can be seen that researchers often propose traffic light control solutions for isolated intersections, however, for realistic solutions, methods of coordination between intersections must take place in order to avoid the problem of fluidizing an intersection and generating congestion in other neighboring intersections. And finally, regarding the priority which must be given to emergency vehicles, the majority of approaches do not consider it.

Table 1. Different characteristics of ITS for Traffic Management.

	Ref	Date	objective								Technology				Data collection					Network type			P	Tool
			Reduce traffic jams	Reduce cybersecurity concerns	Throughput maximization	Vehicle stop minimization	AWT minimization	AFC & Emission minimization	ATD & ATT minimization	Effective crowd management	IoT	AI	Big Data	Cloud or Fog Computing	WSN	VANET	Camera	location services	Traffic Map {history data}	Isolated intersection	Multiple intersections	General network	Priority	
Traffic Guidance	[3]	2020	✓						✓			✓						✓				✓	No	VANET
	[4]	2020	✓										✓						✓			✓	No	Apache Spark R-tool
	[5]	2019						✓	✓		✓					✓						✓	No	Veins : SUMO, OMNeT++
Traffic Light Control	[7] [1] [8] [2]	2012					✓								✓					✓[1]	✓[2]		No	SUMO
	[9]	2020				✓										✓				✓			No	Veins: SUMO, OMNeT++
	[10]	2018			✓				✓							✓				✓			Yes	SUMO, NS-2
	[11]	2016	✓		✓											✓				✓	✓			
	[12]	2019					✓				✓			✓			✓			✓			No	SUMO Server: M2X IoT Platform
	[13]	2020					✓				✓			✓			✓			✓			Yes	SUMO, OpenCV
	[14]	2017	✓				✓				✓						✓			✓			Yes	OpenCV
Network Traffic	[16]	2017	✓	✓	✓				✓							✓						✓	No	SUMO
	[15]	2019							✓			✓										✓		JADE
	[17]	2019							✓					✓		✓						✓		

5. Conclusion and Future Work

Recent advancements in Big Data, AI, and IoT have created great strength and immense potential for minimizing road traffic management issues. Cameras, WSN and VANET technologies are the common data sources used in smart cities. By involving them on intersections we can collect various road traffic data in real time. AI-based approaches play a promising role in minimizing the problems of efficient road traffic management, especially at intersections which represent the major source of road congestion. Future works can: focus on using AI techniques to invent new solutions that take into consideration the different road users in real life (vehicles, pedestrians, bicyclists, etc.), prioritize emergency vehicles such as ambulances, firefighters, and police cars to prevent loss of life, damage or destruction of property, use cloud computing to reduce the cost and improve the efficiency of road traffic management systems, and give strict consideration of the need to minimize emissions, fuel consumption, and environmental pollution toward a green city.

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