From Smart Parking Towards Autonomous Valet Parking: A Survey, Challenges and Future Works

Muhammad Khalid, Kezhi Wang, Nauman Aslam, Yue Cao, Naveed Ahmad and Muhammad Khurram Khan

Abstract—**Recently, we see an increasing number of vehicles coming into our lives, which makes finding car parks a difficult task. To overcome this challenge, efficient and advanced parking techniques are required, such as finding the proper parking slot, increasing users' experience, dynamic path planning and congestion avoidance. To this end, this survey provides a detailed overview starting from Smart Parking (SP) towards the emerging Autonomous Valet Parking (AVP) techniques. Specially, the SP includes digitally enhanced parking, smart routing, high density parking and vacant slot detection solutions. Moreover, the AVP involves Short-range Autonomous Valet Parking (SAVP) and Long-range Autonomous Valet Parking (LAVP). Finally, open issues and future work are provided.**

Index Terms—**Autonomous Parking, Smart Parking, Long-range Autonomous Valet Parking (LAVP), Short-range Autonomous Valet Parking (SAVP)**

I. Introduction

THE integration of Internet of Things (IoT) with cloud computing motivates the development of automated valet parking and smart cities [1]. These services include real-time processing, location awareness, data and load management for environment sensing and coordination, which may have a direct effect on human mobility and future transportation system [2], [3]. Normally, people tend to travel using their own vehicles due to a higher rate of comfort and availability [4]. According to recent transport statistics of Great Britain, 78% of transportation is covered by private transport means, while the remaining 22% is covered by other public services, e.g., bus and rail [5].

According to the British National Travel Survey, a typical household derives 361 hours a year [6] and on average the vehicle is parked for 95% of its lifetime [7]. To accommodate the increasing number of vehicles, a large place is normally used in urban areas for parking purposes [8]. The parking locations and spaces are normally selected in comparison to human-to-vehicle ratio. For example, about 31% of total land is used for parking in San Francisco, 16% in London, 18% in New York and 81% in Los Angeles [9], [10].

The car parking services can generate a good revenue for corresponding parties but also create the hurdles in the development of infrastructure [1]. The management of supply and demand in the parking system is always an alarming issue. The development of Smart Parking (SP) [11] and advances in Information Communication Technology (ICT) facilitate parking management, as depicted in Fig. 1.

If the driver already has information about availability of parking slots at a car park, less fuel consumption can be achieved towards car parking through a precise navigation [12]–[14]. Additionally, the vehicle guidance system can avoid the unnecessary roaming of vehicles in search of car parks. These solutions help to alleviate environmental pollution and traffic congestion [15]–[17].

The optimal management of utilization of parking slots plays an important role in solving parking problems [18]–[20]. Such proper utilization can bring a significant benefit in alleviating congestion rate [21]. The advanced parking management techniques can benefit both drivers and car park

TABLE I
List of Abbreviations

SP	Smart parking
AVP	Autonomous valet parking
LAVP	Long-range autonomous valet parking
SAVP	Short-range autonomous valet parking
AV	Autonomous vehicle
D/P	Drop-off/Pick-up spot
ICT	Information communication technology
IIHS	Insurance institute for highway safety
DEP	Digitally enhanced parking
HDP	High density parking
SR	Smart routing
VSD	Vacant slot detection
RTR	Real time reservation
STR	Static time reservation
CRC	Central request centre
SASs	Smart allocation systems
PM	Parking manager
MILP	Mixed integer linear programming
TA	Trusted authority
IPA	Intelligent parking assistant
OBU	On board unit
RSU	Road side unit
PGI	Parking geographic information system
CPN	Car park network
RFID	Radio frequency identification

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[1]Infrastructure may include traffic design system, road conditions, car park deployment and vehicles to parking ratio.

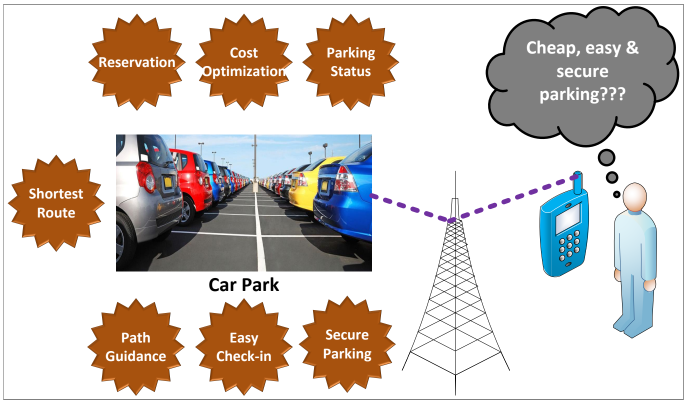

Fig. 1. Smart Parking through Mobile Phone System

operators:

- It provides drivers with parking suggestions with low cost in terms of price and distance, which are inadequately studied in traditional parking techniques.
- It improves utilization of parking space by accommodating more vehicles and implementing the profitable policies. Information about availability of parking slots and prices may be monitored through a centralized server and accessed through mobile applications or web services [22].

The operation of parking the vehicle at a fixed parking slot of the car park can be challenging for less experienced drivers [23]. The skill set required and circular driving in tight space, makes parking operation more difficult. Thus parking a vehicle may need some extraordinary skills such as moving the vehicle backward and forward multiple times [24]. Although SP applies some improved parking techniques (e.g., checking parking availability, traffic updates and finding a car park with cheaper cost), drivers still feel uncomfortable due to the requirement of human-driven operation [16], [25].

Furthermore, the recent development in autonomous systems with computer vision and sensing has provided potential solutions to transportation challenges, which include safety on wheels, efficiency, fuel consumption, traffic congestion and environmental pollution [26]–[28]. The Autonomous Vehicle (AV) can perform various driving operations without human intervention, including avoiding obstacles, scanning for a vacant parking slot and parking navigation [29]–[31].

In particular, Autonomous Valet Parking (AVP) has been proposed recently which facilitates AV to drop user[2] at a predefined drop-off spot. In the next step, the AV starts moving towards the selected car park, and performs route selection and parking operation autonomously [32].

The AVP can be divided into Short-range Autonomous Valet Parking (SAVP) and Long-range Autonomous Valet Parking (LAVP). In SAVP, users leave AV at car park entrance (e.g., the entrance may be co-located with drop-off spot) [33]. The AV scans through available parking slots using modern vision techniques; avoids obstacles with the help of sensing technologies; and gets parked in designated parking slot using autonomous car-manoeuvring techniques [34]. Moreover, using the modern localization techniques, SAVP can be performed in multi-story car park [35], where the AV may be trained at least once before performing SAVP operations autonomously [36], [37]. In comparison, LAVP can deliver a higher rate of comfort and convenience to users. For LAVP, the user is able to leave AV at the centre of the city (or any designated drop-off spot), after which the AV travels from drop-off spot to car park with the appropriate route. The main acronyms used in this paper have been defined in Table I.

[2]In this paper, the term “driver” and “user” are inter-exchangeable. This is because we envision that there is no ownership of AVP, thanks to the vehicular sharing mode in long-range parking. The term “driver” is normally used for traditional parking, smart parking and AVP supporting short range parking.

A. Motivation

In urban areas, a limited number of car parks are normally available. Also, tight space for parking a vehicle, high cost and congesting rate are the reasons that need immediate attention [38]. On average, 30% of traffic is caused by vehicles searching for parking slots at car parks. A driver on average spends 6 minutes in the UK to find a parking slot, reported by JustPark [39]–[43]. Moreover, according to a recent report by the insurance institute for highway safety, more than 20% of the car accidents occur in commercial parking areas. Also, the production rate of auto-mobiles has been doubled over the last decade, and it is quite challenging to accommodate the increasing number of vehicles in the current parking infrastructure. The application of emerging techniques like machine learning and intelligent sensing in car parks and roadside may effectively decrease the parking search time and improve mobility. Also, the proper parking management can have a major impact on the overall parking activities as well as reduce the congestion and accident rate [44]. To this end, the comprehensive survey about the current parking solutions is highly expected, which this paper will deliver to the readers.

B. Previous Survey Papers on Parking

The previous survey papers on parking are summarized as follows:

- The paper of [20] focused on information collection, system development, and service dissemination in SP.
- The paper of [45] discussed high-density parking solutions.
- The paper of [46] focused on SP system management facilities with respect to the normal parking solutions.

One can see that the previous surveys mainly focused on SP and lack the investigation on some important points, e.g., smart routing and congestion reduction. Also, they have not covered two other emerging techniques, i.e., SAVP and LAVP, where the framework, methodology and features are discussed in this paper. A comparison of previous survey papers is carried out in Table II.

C. Contribution of this Survey

The main contributions of this survey are as follows:

TABLE II
COMPARISON OF PARKING SURVEYS

Taxonomy	Smart Parking	Vacant Slot Detection	Route Planning	High Density Parking	AVP		Year
					SAVP	LAVP	
This survey	✓	✓	✓	✓	✓	✓	
A survey of smart parking solutions [20]	✓	–	✓	–	–	–	2017
A survey on automated valet parking [45]	–	–	–	✓	✓	–	2017
A survey on intelligent car parking solutions [46]	✓	–	–	✓	–	–	2013

- We first introduces the parking models, including traditional and smart parking.
- We then provide a comprehensive study of the recent research in SP solutions, including digitally enhanced parking, high-density parking, vacant slot detection techniques and route planning solutions.
- Next, we review AVP techniques, including SAVP and LAVP, with their procedure, features and working models.
- Finally, we provide the challenges and future directions, to motivate more innovative research in this field.

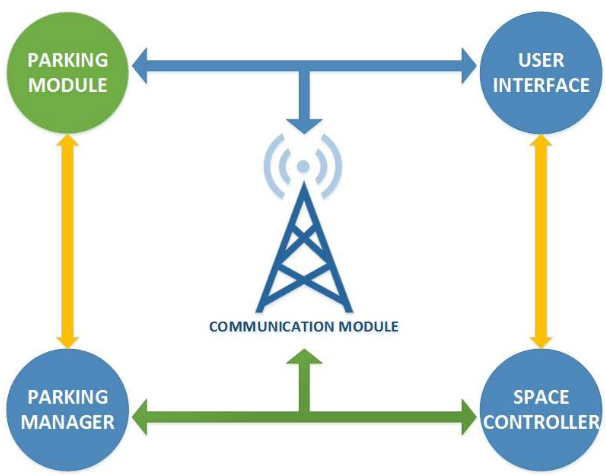

Fig. 2. A General Smart Parking Model

D. *Structure of the Survey*

The overall structure of this paper is described in Fig. 3. Specifically,

- **Section II: Parking Module** consists of a detailed introduction to the parking components in traditional parking and SP.
- **Section III: Smart Parking** involves a detailed review of SP solutions including cloud based and sensor based SP, vacant slot detection techniques, smart routing methodologies and high density parking mechanism inside dense parking areas.
- **Section IV: Autonomous Valet Parking** discusses the innovative autonomous parking techniques, i.e., SAVP and LAVP. Also, their working model and procedures are explored.
- **Section V: Challenges & Future Directions** presents the challenges which aim to inspire the future research in this field.
- **Section VI: Conclusion** concludes this survey paper by providing a summary of start-of-the-art technologies in smart and autonomous car parking.

II. PARKING MODULE

A. *Traditional Parking*

A few decades ago, the availability of parking information about location, pricing and vacant spaces was not adequately addressed [47]. There was no prior information about where to park, how much it will cost and how far it is from car park. In traditional parking, a driver needs to go to every car park, and checks each parking slot in search of a free space [48]. On one hand, it costs highly in terms of time as well as fuel consumption and some users also suffer from the hassle of moving the vehicle into the car park [49]. On the other hand, it produces much environmental pollution due to long parking time [50]. Therefore, one of the major limitations for traditional parking may be the non-availability of parking information [51]. In this case, the driver may be unable to pre-book the parking slot, or the parking slot can not be booked in real-time when the user is approaching the car park.

B. *Smart Parking Model*

A general SP model consists of the following elements [52], as shown in Fig. 2.

*a) **Parking Module**:* This module ensures and defines all the operations inside the car park. For instance, it can scan parking slots and update the information to the vehicle in real time. Also, this module can inform the driver, if a vehicle is parked outside slot premises.

*b) **User Interface**:* This module connects the driver to the manager module and parking servers. It can provide the driver with an easy interface to perform certain operations including checking real-time information about available parking slots, reserving the parking slot, processing payment for a reserved slot and receiving route guidance from the parking module.

*c) **Communication Module**:* This module performs certain operations like information exchange, encryption, controlling errors and assessing reliability of data. It ensures to address connectivity issues and conducts communications between vehicles, parking managers and car parks.

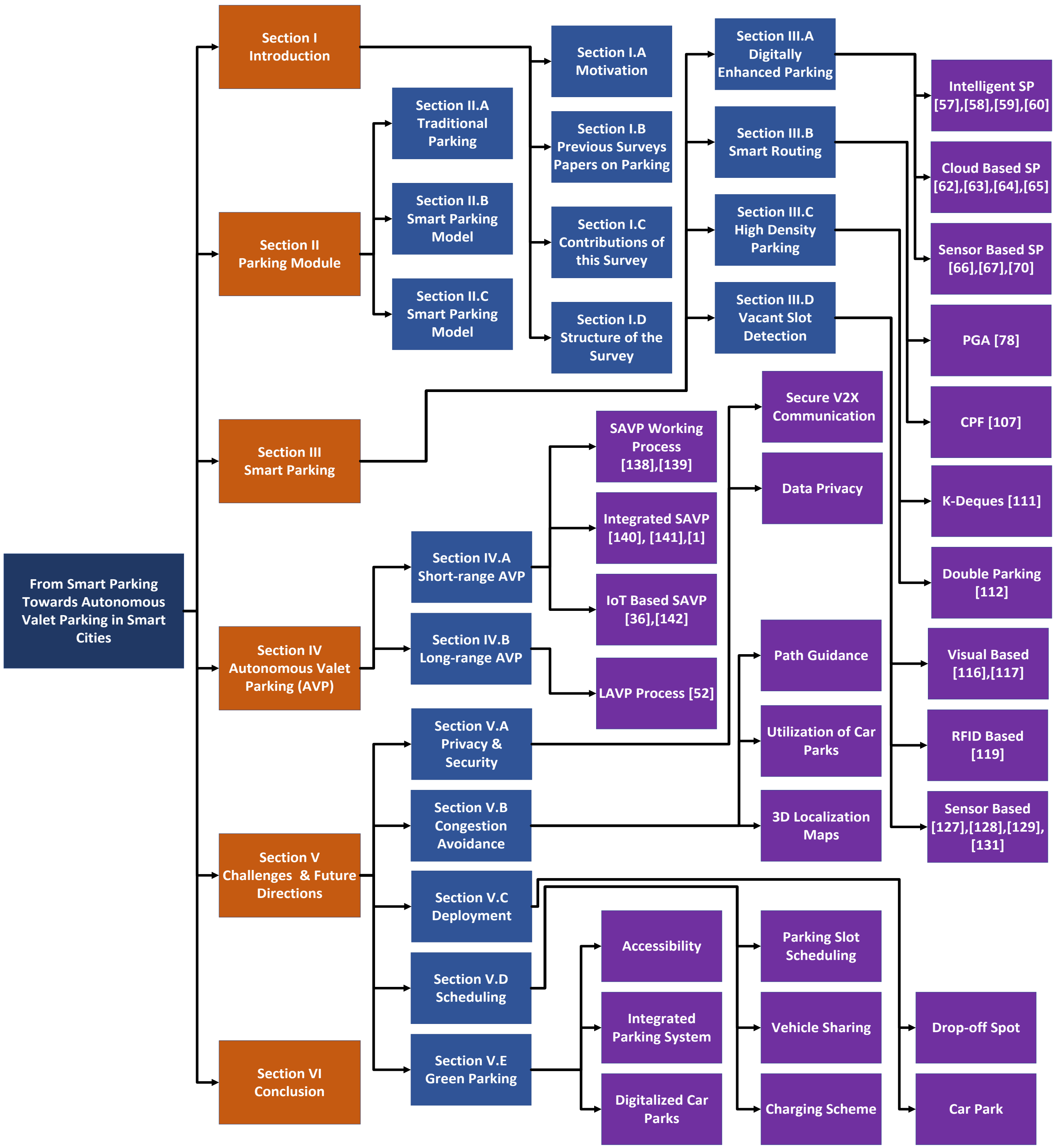

Fig. 3. A Taxonomy of Smart Parking & Autonomous Valet Parking Solutions

*d) **Parking Manager**:* This module carries the data management about reserved parking slots as well as the transaction record of the user for each occupied parking slot. It also communicates the overall statistics about car parks to other modules.

*e) **Space Controller**:* This module detects and analyses the parking slot in terms of whether a certain slot is vacant or occupied. It also monitors the overall parking area through a combination of different sensors.

In comparison to traditional parking, smart parking provides drivers with pre-parking information like location, availability of parking slots and fees. Also, it provides the facility of pre-arrival and real-time booking. The challenges in SP include the analysis of route in real-time and finding a parking location that is usually far away from the city centre. In this case, the driver may walk or take a bus on the way back after they park the car.

C. *Autonomous Valet Parking*

In the early stage, AVP was applied to provide limited parking assistance, where the driver remains inside the AV and intervenes in the process, which may not be considered as the fully autonomous system. Fig. 4 summarize different levels of autonomous parking. If the driver fully supervises parking activity, it is referred as "Level 1b" parking. In level 2, drivers can stay out of the vehicle to monitor and control the overall parking process through smart devices, e.g., mobile phones. The level 3 applies advanced sensing and 3D mapping technologies to avoid obstacles and find out the best route towards car park [54]. Then, the state-of-the-art path generation [55] and precise detection techniques [56] have extended AVP towards large scale areas. In this scenario, it can be referred as "Level 4a", where a driver leaves AV at car park entrance and then AV is navigated towards a vacant slot [57]. The disadvantage of this system may be that the driver has to approach a car park and then drops the AV there, however it can save time to find a parking slot.

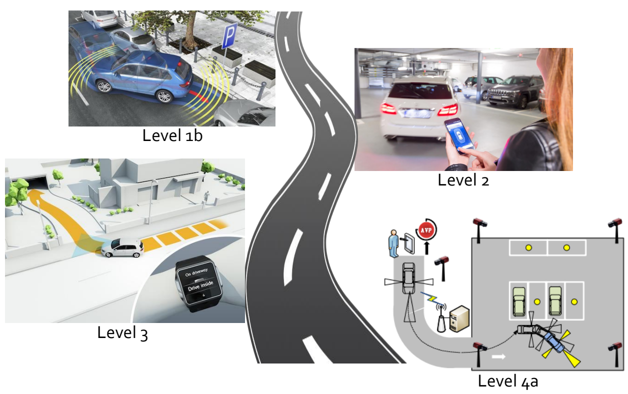

Fig. 4. AVP at Low Autonomous Level [53]

III. Smart Parking

The exponential increase in the number of vehicles without proper management is alarming for existing infrastructure. The solution towards proposing efficient parking management has become an uttermost need these days. Currently, SP solutions have minimized congestion and pollution rate as compared to traditional parking approaches. As the automotive industry is moving towards autonomy, the parking techniques also require much attention. This section will discuss smart parking techniques including Digitally Enhanced Parking (DEP), High Density Parking (HDP), Smart Routing (SR) and Vacant Slot Detection (VSD). A comprehensive analysis of smart parking techniques discussed in section III has been provided in Table III.

A. *Digitally Enhanced Parking*

Solutions under this branch can save resources and facilitate parking in a timely manner, via pre-arrival information and pre-reservation. These techniques are mainly divided into intelligent SP, cloud-based SP and sensor-based SP. Most of the techniques explained in this section take real-time data of an individual user to make the decision. To make the SP system work effectively, it is also important to consider previous/historical data of other users as well as information, e.g., car parks. Using previous data with machine learning techniques may help make faster and efficient decisions.

*1) **Intelligent Smart Parking**:* Intelligent smart parking allows users to reserve parking space prior to arrival at the car park. It intelligently assigns a car park for drivers with parking demand, based on driver's preference and location. These preferences may include the length of stay, time of parking, previous parking history and congestion rate in the city. We give some related work as follows:

i-Parker [58]: The i-Parker is mainly based on intelligently allocating resources, defining prices and reserving parking slots when necessary. The main contribution of i-Parker is that it can make the reservations based on the lowest parking price and searching time. The i-Parker combines the concept of Real Time Reservation (RTR) and Share Time Reservation (STR). RTR and STR allow drivers to select a parking spot beforehand. RTR continuously updates vehicles with the best parking slot until the vehicle reaches the car park. In STR, the driver selects a specific parking and time slot as per user convenience. The architecture of this system has been categorized into Central Request Centre (CRC), Parking Manager (PM) and Smart Allocation System (SAS). The CRC receives a parking request, and then puts it to SAS for parking slot allocation. The PM acts as an interface between SAS and parking authorities. SAS consists of a pricing engine, sensors, data centre, and virtual message signs. Also, the queuing model is divided into dynamic and static parking. The i-Parker uses Mixed Integer Linear Programming (MILP) to minimize the monetary cost for the users.

Smart-Park (S-Park) [59]: The S-Park provides real-time information about car parks as per drivers' convenience. S-Park are mainly composed of a Trusted Authority (TA), On-Board Units (OBUs) and Road Side Units (RSUs). The TA is responsible for authorization of both OBUs and RSUs. Additionally, OBUs are the units installed on the vehicles which are liable for communication with other vehicles and

RSUs. Also, the RSUs are responsible for registration of OBUs and to provide the real-time parking information to other vehicles. Note that the RSUs are deployed in such a way that they can fully cover the area and also interact with each other at a certain point. This system also uses a bi-linear pairing technique.

Smart Parking Allocation & Reservation [60]: This work assigns and reserves an optimal parking slot depending on the cost function. The components of this system include Parking Geographic Information (PGI) system, Driver Request Processing Centre (DRPC), Parking Resource Management Centre (PRMC) and Smart Parking Allocation Centre (SPAC). The PRMC updates real-time parking information, and delivers it to end users via the Internet or VMS. Similarly, DRPC is responsible for collecting parking requests and monitoring the recent parking allocation resources. This system considers the current road condition and car park information into account, and then suggests an optimal car park navigation. The proposed algorithm solves MILP to select an optimal parking slot, on the basis of parameters and information provided by the user.

Intelligent Parking Assistant [61]: Intelligent Parking Assistant (IPA) collects the information about on-street parking slots. It shares the real-time occupancy information about parking slots with the vehicles on road and parking management system. IPA provides a facility to book a parking before arrival and it can only be accessed by authorized drivers with valid login credentials. Once a parking slot has been booked, a reservation number is generated and delivered to the driver in a secure way [62]. In special cases if the arrival is delayed due to traffic congestion, the parking reservation is kept on hold for a certain amount of time. Also, the authentication for reserved slots is made possible by deploying Radio Frequency IDentification (RFID) reader to read and identify the booking tags.

*2) **Cloud Based Smart Parking**:* The cloud-based SP exchanges information with the cloud centre, and provides drivers with city-wide car park locations and recommendations. We give more details as follows:

Campus Parking with Quality of Experience (QoE) [63]: It focuses on the efficient use of the existing parking slots of car parks on a sharing basis by drivers, with day and night shifts. This scheme is specifically proposed for the university parking scenario, considering the coordination between university and surrounding parking slots. It is considered that there are certain contracts that exist between university administration and private parking owners. This technique focuses on two parts: 1) How many parking slots have to be reserved in day-time for night-time users; 2) How the first-come-first-serve method can be replaced by the more efficient solution.

IoT Based Smart Parking [64]: This parking system suggests a free parking slot with low cost, where the cost is based on distance and availability of parking slots. The system adopts Wireless Sensor Network (WSN) and RFID technology. Here, the RFID helps in counting the number of free parking slots, while the sensor monitors the occupation of parking slots. Besides RFID and WSN, this system uses a cloud data centre to store the data received from local units, which are located at each car park and collects information about parking slots. On the network layer, this system uses Car Park Network (CPN) architecture, based on wireless as well as wired communications. The CPN is also integrated with RFID and WSN in such a way that it provides the parking slots availability in real time.

SMS Based Smart Parking [65]: Short Messaging Service (SMS) based SP is primarily designed for vehicles which do not have the modern system to go through reservation autonomously. Here, the reservation can be achieved with a simple mobile device capable of sending text messages. The proposed system can reserve a parking slot as well as gaining entry to the car park through SMS. After a driver sends an SMS, it is processed by a device called the Remote Terminal Unit (RTU) to send out parking slot reservation information[3]. The reservation is valid for a certain period, and if the driver does not confirm parking in the specified time frame, it will be cancelled. Additionally, the parking area is controlled by an automated device called Peripheral Interface Controller (PIC). It forwards the stored information about empty parking spaces and provides login credentials for authentication at the entrance. The challenge in this system is that it does not provide city wide parking information and the user is unable to select a parking place as per user needs.

Cloud-IoT Smart Parking [66]: This system focuses on higher revenue generation in SP. It introduces the Parking Service Provider (PSP) to generate more revenues from the efficient utilization of parking slots. PSP, on one hand, is beneficial for car park operators in terms of higher revenue. On the other hand, it tends to suggest parking slots with a lower price. PSP announces availability of parking slots to the cloud and such information can also be accessed by drivers[4]. Similarly, parking slots can be booked earlier from arrival for a specified time slot. As all vehicles and car parks are connected to the cloud system, vehicles can easily find the nearest available car parks. Note that the specified car location can be accessed by PSP, so that it can instruct the vehicle towards an efficient path[5].

*3) **Sensor Based Smart Parking**:* Here, sensor nodes are deployed around the car park, to monitor car park and pass on monitoring information to the main server.

Accelerometer [67]: This system is designed to overcome parking problems in busy urban areas. Here, parking slots are monitored with the help of a smart phone with an embedded sensor called an accelerometer. Therefore, it supports neither pre-reservation option for parking nor any remote services. Upon the parking event is detected, information is disseminated in two ways: 1) through the Internet to the remote server; 2) over device-to-device links with the help of nearest available Wi-Fi spots. Then, the information is shared with drivers searching for vacant parking slots.

WSN [68]: This system helps the vehicle to find a free

[3]The reservation information includes parking slot location, number, and password which provides entry to the parking area.

[4]It includes parking cost, distance to car park and available time duration.

[5]The efficient path means a path with lower cost, less congestion and shorter distance.

parking slot through WSN. It comprises embedded web server, central web server, sensors, and mobile application designed for parking [69]. Each parking slot is covered by a single sensor node [70], which continuously detects the status of the parking slot. The real-time information from the sensor node is then forwarded to the embedded web server. The status information of citywide parking location is collected at the centralized web server, thus the real-time information about parking slots is available on the centralized server. This can be further accessed by drivers through mobile application.

RFID [71]: The RFID in combination with WSN is used to let the driver be aware of the nearest available car park. A customized software is specifically developed to collect information about the real-time status of parking slots. It provides the user with much convenience, e.g, to provide the facility to pay parking fee through e-wallet. This system also has the capability to support other parking applications, e.g., the time frame of parking slots, reservation and other relevant information if a vehicle is parked in the wrong place.

B. *Smart Routing*

Route planning or Smart Routing (SR) in every network model acts as an important factor towards efficiency [72]. A good route planning solution helps the vehicle to reach its destination optimally [73]. Route planning plays an important role in SP as well [74], [75]. An optimal route planning in the transportation system tends to reduce fuel consumption, takes less time and produces lower CO_2. Route planning helps vehicles to avoid congested routes [76], [77]. The SR techniques being used here are mostly dependent on a static route with variation in traffic rate. Since development works may be carried out in the city centre these days. It is important to use dynamic SR methodologies for parking scenarios, like reinforcement learning. It has two benefits, 1) Processing routes in real-time 2) One user can learn from the experience of another user. It may positively impact the environment and fuel cost.

Parking Guidance Algorithm (PGA) [79]: PGA primarily aims to consume less energy and control the emission of CO_2. It divides SP guidance system into five parts which includes parking slot, management system, central server, personal navigation device, and the driver. The parking request is initiated by a driver and location information is obtained from the personal navigation device. The central server is then requested for parking information. Next, the parking management system provides real-time information to the central server, and also shares it with the driver. The same hierarchy is used for reserving parking space once parking information is received[6]. The SP guidance system tends to update the parking data in real-time, and hence provides the user with comfortable parking experience [106].

Collaborative Path Finding [107]: It uses A-star algorithm for path-finding while the city is represented through a combination of square grids, where each square grid shows a part of the city. This algorithm uses the idea of reversing the path in the A-star algorithm, which helps in finding the exact distance towards the desired destination. The reversing A-star provides multiple possibilities at each square grid. An ordering technique is applied to the set of possible paths, to get rid of unnecessary routes and help in constructing a specific path from the initial point towards the destination. This system also combines multiple routes and presents it as a group, to select one route from a group of routes to guarantee minimum congestion rate. If congestion is detected at any stage on a specified path, a new collective path is constructed to replace the current one.

[6]The parking information includes hourly fee, distance to the parking area, traffic and road condition.

C. *High Density Parking*

The High Density Parking (HDP) either decreases the use of extensive land for parking, or utilizes the existing car park to accommodate a higher number of vehicles. It is assumed that HDP can increase the capacity of existing parking by 50 percent [108]–[110]. The HDP techniques cannot be directly applied to all the SP scenarios. Some portions of the car parks may be reserved for AVs. These AVs can move around to other slots when needed. The HDP parking techniques are very efficient for fully autonomous car parking in terms of space utilization. Some HDP techniques are discussed as follows:

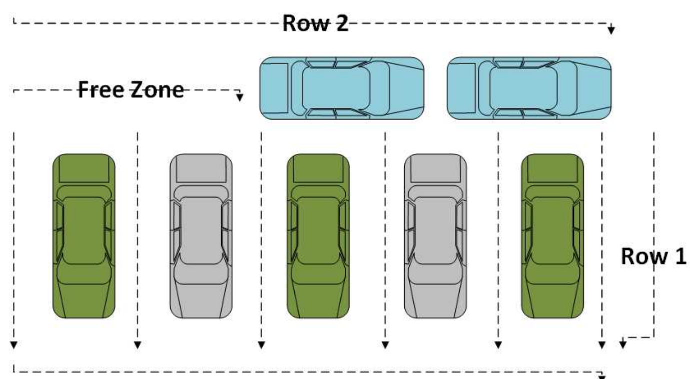

Fig. 5. High Density Parking

k-Deques [111]: In k-deques, parking slots are located perpendicular to main driveways and accommodate both AVs and non-AVs. It assumes that the length of the parking slot is doubled as that of its width, and k-deque is deemed as a double ending parking slot with k parking slots. This problem is presented through MILP and the results show that it can increase the capacity of existing car parks by up to 25%.

Double Parking [112]: Double parking technique uses the existing roadside parking spaces as depicted in Fig. 5. Many double parking techniques have been proposed in [113], [114], featured with 2-row mechanisms. As presented in Fig. 5, row-1 is specified for non-AVs but AVs can also be parked here, as they are quite flexible in moving forward and backward in the time of need. AVs can only be parked in row 2. The reason for parking AVs only in row 2 is that an AV can be moved forward and backward autonomously if any of AV from row 1 needs to enter or exit the car park.

TABLE III
SMART PARKING ANALYSIS

Smart Parking									
				Storage				Cost	
	Category	Mechanism	Res.	c	d	Connectivity	Security	S	D
Digitally Enhanced Parking	Intelligent SP	i-Parker	RT/ST	-	y	2G/3G/4G	**	y	y
		S-Park	RT/ST	-	y	802.11	*	-	y
		SP A&R	RT	y	-	2G/3G/4G	-	y	-
		IPA	ST	-	y	802.11	*	y	-
	Cloud Based SP	Campus Parking	ST	y	-	802.11	**	y	-
		SMS based Parking	ST	y	-	2G/3G/4G	**	y	-
		IoT SP	RT	-	y	2G/3G/4G	-	-	y
		Cloud-IoT SP	RT/ST	-	y	802.11	*	-	y
	Sensor Based SP	Accelerometer	ST	-	-	802.11	*	-	y
		RFID	ST	-	-	802.11	**	-	y
		WSN	ST	-	-	802.15.4	**	-	y
Smart Routing	PGI		RT/ST	y	-	802.11	-	y	-
	Collaborative Path Finding		RT	y	-	802.11	-	-	y
High Density Parking	K- Deques		ST	-	y	802.11	*	-	-
	Double Parking		ST	y	-	802.11	*	-	-
Vacant slot Detection	Visual	AVM	-	y	-	3G/4G	**	-	y
		UAV	-	-	y	3G/4G	**	-	y
	RFID		-	y	-	802.11/2G	**	y	-
	Sensor	Fusion	-	y	-	-	*	-	y
		AMR	-	-	y	-	*	y	-
		IoT	-	-	y	2G/3G	*	y	-
		Magnetometer	-	-	y	-	-	y	-

- † In storage column, c is centralized & d as distributed.
- ‡ In cost column, S is static & D as dynamic.

D. *Vacant Slot Detection*

Recent techniques can detect vacant slots in real time, while others may be managed by parking controller [115].

*1) **Visual Based**:* This category discusses Vacant Slot Detection (VSD) techniques based on visual technologies.

AVM [116]: This kind of automatic parking slot detection is based on the Around View Monitor (AVM) system. In AVM, four fish-eye cameras are equipped for a vehicle to provide a wider view of the parking slot. This system detects parking slots through Line Segment Detector (LSD). Furthermore, AVM uses image segmentation techniques and stereo vision algorithms to detect and avoid small obstacles around parking slots.

UAV [117]: Unmanned Autonomous Vehicle (UAV) takes images that can be further processed to check: 1) The number of vehicles parked in a car park; 2) Number of the vacant slots of a car park within a certain time duration. The detection uses a novel method to detect vacant and occupied slots in car parks via taking density values of an image to detect vacant parking slots, which is efficient in terms of cost and time [118].

*2) **RFID Based [119]**:* This scheme uses Battery Assisted Passive (BAP) generating 2 RFID tags to determine the status of parking slots at car parks. The generation of 2 RFID tags are considered as having lower energy consumption with a relatively higher throughput [120], [121]. It also has a low cost with the capability of accepting multiple readings simultaneously, where the tags can be within 2 to 10 meters. They are deployed on ground level, of which batteries are replaced with solar cells [122]. A vehicle is parked in a slot in such a way that it covers up the tag, and is unable to receive the required light meeting the threshold value. In this case, it stops transmitting data and the system automatically knows that a certain slot is occupied [123]–[125]. In many cases, the RFID tag may receive enough light for data transmission though that the slot may be occupied. In the former case, this system still faces certain challenges and issues [126].

*3) **Sensor Based**:* **Fusion Sensor [127]:** This system fuses with AVM and ultrasonic sensors, to detect the vacant and occupied parking slots. This technique can be divided into three steps: 1) Slot marking detection; 2) Slot occupancy detection; 3) Tracking procedure for slot markings. In the initial step, different AVM image sequences are used to detect the markings of parking slots. Then, the data about parking slots occupancy is achieved using ultrasonic sensors. During image classification, each image is considered as a single cell among the grid. In the final step, the marking of parking slot can be tracked by estimating the position of the selected parking slot when a vehicle is moving in. A parking slot consists of multiple lines with the same or different orientation. The Directional Chamfer Matching (DCM) is used to fuse the data from motion sensors and AVM images.

AMR Sensor [128]: This technique uses Anisotropic Magneto-Resistive (AMR) sensors installed on road-side parking slots. The slot detection is categorized as a binary pattern recognition problem (i.e., either occupied or vacant). The primary feature for this system is to train magnetic signals for classification criteria. It needs to go through the following steps: 1) To analyse the properties of received magnetic signal; 2) Distance discrimination method is used to train classification rules and pre-classify the obtained data; 3) Designing detection algorithm for parking based on obtained classifications.

TABLE IV
SMART PARKING ARCHITECTURES

Architecture	Communication Mode	Sensing Technology	Route Optimization	High Density Parking	Reservation	Eco-Friendly	Cost Effectiveness	QoE	AVP
Kotb [58]	Cellular/4G	GPS	✓	–	✓	High	High	High	–
Spark [59]	802.11	RSU	–	–	✓	Moderate	Moderate	Moderate	–
Yanfeng [60]	Cellular/4G	Magnetometer	✓	–	✓	Moderate	High	High	–
Ipa [61]	802.11	RFID	–	✓	–	High	Low	Moderate	–
Wynita [63]	802.11	RSU	–	–	✓	–	–	Moderate	–
Thanh [64]	Cellular/4G	WSN RFID	✓	✓	–	Low	Moderate	Moderate	–
sms [65]	Cellular/GSM	WSN	–	–	✓	Low	Moderate	Low	–
Yacine [66]	802.15 GSM	WSN	✓	–	✓	Low	High	Moderate	–
Rajabioun [12]	Cellular/4G	RSU	–	✓	✓	Moderate	Moderate	High	–
Schwesinger [36]	Cellular/4G	Magnetometer RSU	–	✓	✓	High	Moderate	High	✓
Mehmetkr [52]	802.15	Magnetometer WSN	✓	–	✓	High	Moderate	Low	✓
Jianbing [78]	Cellular/4G	WSN RSU	✓	–	✓	Moderate	High	High	–
Jong-Ho [79]	802.11	RSU	✓	–	✓	High	Low	High	–
Azevedo [80]	Cellular/4G	GPS	–	✓	✓	High	High	Moderate	–
Banzhaf [45]	Cellular	RSU GPS	–	✓	✓	Moderate	Moderate	High	✓
Evenepoel [11]	Cellular	GPS	✓	–	–	Low	Moderate	Low	–
Polycarpou [81]	Cellular/GSM	GPS WSN	–	–	✓	Low	Moderate	Low	–
Delot [82]	802.11	RSU	✓	✓	–	Moderate	Moderate	High	–
Zhang [83]	802.15	WSN	–	✓	✓	Low	Moderate	Low	–
Yoo [84]	802.15	WSN	–	–	✓	Moderate	Low	Low	–
Nandugudi [85]	Cellular	RSU GPS	✓	–	✓	High	Moderate	High	–
Villalobos [86]	Cellular	RSU GPS	✓	–	✓	Moderate	Moderate	Moderate	–
Mathur [87]	Cellular	RSU	–	✓	–	Moderate	Low	Low	–
Vishnubhotla [88]	802.15	WSN	–	✓	–	Low	Moderate	Low	–
Verroios [89]	802.11	RSU GPS	✓	–	✓	Moderate	Low	Low	–
Wang [90]	Cellular	RSU GPS	–	–	✓	Low	Moderate	Low	–
Tang [91]	802.15	WSN	–	–	✓	Low	Moderate	Low	–
Yan [92]	802.15	WSN	–	–	✓	Low	Low	Moderate	–
Stenneth [93]	Cellular/GSM	GPS RSU	✓	–	✓	Low	Moderate	Low	–
Samaras [94]	802.15	WSN	–	✓	–	Low	Low	Moderate	–
Souissi [95]	802.15	WSN	–	–	✓	Low	Low	Low	–
Rico [96]	Cellular/GSM	RSU	✓	–	✓	Moderate	Moderate	High	–
Suryady [97]	Cellular/4G	GPS RSU	–	–	✓	Low	Moderate	Moderate	–
Pazos [98]	Cellular/4G	RSU	–	✓	✓	Moderate	High	Moderate	–
Mainetti [99]	Cellular 802.11	GPS RSU	✓	–	✓	High	Moderate	High	–
Chinrungrueng [100]	Cellular 802.11	RSU	–	–	✓	Moderate	Moderate	Low	–
Zhanlin [101]	Cellular 802.11	GPS RSU	✓	✓	✓	High	Moderate	High	–
Demisch [102]	Cellular/4G	RSU GPS	–	–	✓	Low	High	High	–
Alhammad [103]	802.11	RSU	–	✓	✓	Low	High	Moderate	–
Raichura [104]	Cellular 802.11	RSU	–	✓	–	Low	Moderate	Low	–
Zhao [105]	802.11	RSU	–	–	✓	Low	Moderate	Low	–

Ultra-Sonic Sensor [129]: The ultrasonic-sensors in combination with the IoT technology, is used to detect vacant and occupied parking slots. With collected information, sensors can continuously update the server via the Internet about statistics of parking slots [130]. Two ultrasonic sensors are used for each parking slot, where the first one is deployed in front of the vehicle. A threshold is set for each sensor to detect a vehicle in the designated parking slot. The parking slot is only shown as occupied, if both sensors show the presence of a vehicle. However, the limitation of this system is that if any of the two sensors stop working or could not send accurate data at a certain time, then the data from a single sensor cannot be considered authentic for deciding the status of the parking slot.

Magnetometer Sensor [131]: This system is designed to minimize the searching time of car parking and can detect the free car park slots seamlessly. This system uses sensors like magnetometer and accelerometer to detect the car park with vacant slots.

Apart from SP techniques discussed in Section III, Table IV also analyses various SP architectures with respect to route optimization, HDP, reservation, etc.(2010-2019)

Next, we will introduce autonomous valet parking.

IV. Autonomous Valet Parking

AVP is proposed to apply modern ICT techniques to cope with scheduling, path planning and reservation challenges in real time [132]. With the increase of the number of vehicles, more traffic congestion and parking problems may arise in near future[7] [133]. With the help of AVP, the user can leave AV at a certain point, after which the AV moves towards parking slots in full autonomous mode [134]. AVP is designed to minimize congestion and to deliver the convenient and economical parking systems. Depending on urban city structure, mobility and traffic scenarios, the AVP can be divided into two subsections:

- Short range Autonomous Valet Parking (SAVP); and
- Long range Autonomous Valet Parking (LAVP).

We will discuss each of the above in the following.

A. *Short-range Autonomous Valet Parking (SAVP)*

SAVP benefits from the recent development of computer vision and autonomous car-manoeuvring techniques. It has addressed many parking issues where space for parking operations is found to be limited. It can be used in fully autonomous car parks, where existing parking space can be utilized for an extra 30% to 40% vehicles. For SAVP, AV has to be trained to reach the car parking slot and the training can be performed under human supervision [135]. Recent advancements in machine learning techniques has made it possible to achieve considerable performance in complex parking scenarios [136].

For SAVP, in initial steps, AV is parked under supervision to familiarize with the new area and surroundings. This operation is performed at least once to guide AV to the proper parking slot. Then, AV may be parked in complete autonomous mode after training. The machine vision technologies can enable AV to scan for objects in proximity and perform necessary manoeuvring and navigation during the parking. The recent AVP system is also capable of scanning for available car parks slot by slot and floor by floor in case of multi-story car parks in the fully autonomous mode [137]. Research in [138] provided valuable recommendations on parking slots status, which can save parking time to a large extent. The work in [139] addresses the coordination of AV at car parks with application of Vehicle-to-Grid (V2G) communication, where all the AVs are electrified. Next, we will introduce more details of SAVP:

*1) **SAVP Working Process**:* Once the user initializes the parking request, a reservation ticket from AV is forwarded to the Scheduling Centre (SC). The AV also shares the current location with SC. Then, the SC recommends AV to the most suitable car park which is near to the user's workplace. Next, the user can leave AV at the car park entrance. Then the AV moves autonomously towards the selected parking slot. Similarly, on departure, the user requests the AV back and it can be collected by the user at car park entrance. In the above process, the SAVP is mainly responsible for moving the AV from the parking slot to the entrance of the car park and from the entrance of the car park to the parking slot.

*2) **Integrated SAVP**:* Next, we explain some contributions in integrated SAVP.

AVP as Integrated Travel Assistant (AVP-ITA) [140]: This system proposed the integration of AVP with an on-board travel assistant. The AVP being part of the travel assistant provides various services while travelling and parking. The travel assistant increases the level of user comfort specifically during long journeys, and increases battery efficiency for Electric Vehicles (EV). In terms of parking, this technique combines the car park searching operation with vehicle manoeuvring to take full advantage of AVP facilities. It can be applied to a fully automated vehicle to perform automated parking and manoeuvring operation. This system also applies the mobile phone to control AV and the camera to detect parking slot occupancy and the cameras installed in car parks can detect vacant parking slots and share this information with AV. Also, with the help of sensors deployed on AV and in car parks, the AV can easily move inside the parking area.

k-stack High Density AVP (k-stack AVP) [141]: This technique is proposed to improve the occupancy problem of car parking and to accommodate more AVs. The k-stack has been analysed by number of shunting moves, distance and the pick-up time. It shows that minimizing the shunting moves directly impacts the pick-up time for AV by limiting it to 1 minute when k-stack was used. As this technique is only used for optimizing shunting operations by AV, this system works well in small car parking scenarios. It has not been tested for large scale car parking scenarios.

Secure AVP [1]: This technique proposes a privacy preserving reservation technique for AVP. The aim of the proposed methodology is to mitigate duplicated reservation and avoid disclosing the location of AV. Mitigating the duplicate parking

[7] Parking problems can be referred to finding a suitable parking place/slot. It can also refer to the shortest path towards the car park and with minimum congestion.

issue can prevent denial of service attacks. The computation cost and communication overhead has also been optimized in the proposed methodology. The security model has been defined without using a trusted third-party system. Due to this reason, it may be prone to security threats in large scale scenarios.

*3) **IoT Based SAVP**:* The smart sensors are important in assisting SAVP. Next, we introduce two typical applications.

AVP & E-mobility [36]: This project focuses on extending autonomous driving range and minimizing EV's charging time in SAVP scenarios. The features of V-project develop a prototype for performing autonomous parking using camera and ultrasonic sensors. This project aims to make advancements in parking slots scheduling process, motion planning and infrastructure-based camera calibration. The parking operation has been demonstrated successfully through various indoor and outdoor tests. The results were also obtained through excessive field tests. However, this work lacks in addressing indoor mapping scenarios whereas 3D localization mapping may help for tackling indoor navigation.

Integration of AVP with IoT (AVP-IoT) [142]: This work applies different IoT sensors to carry out efficient and reliable parking operations. It consists of AV, smart devices, Micro Aerial Vehicle (MAV) and cameras to detect parking slots. These components are connected with IoT sensors, and can share information in real time. The vacant parking slot in this technique is detected through computer vision techniques, and the path guidance is provided through MAV.

B. Long-range Autonomous Valet Parking (LAVP)

The above SAVP solutions are limited to a very short range (e.g., working from the entrance of a car park to the parking slot). In comparison, LAVP extends the SAVP to more general cases where the user may leave the car in the city centre or their desired place and then the car may be able to drive to the parking slot autonomously, with the help of path planning and coordinated operation management. On departure, users can be picked up by AV per their specified time and pick-up spot, and then the car can move from the parking slot to the pick-up spot also in full autonomous mode.

We depict the main components of LAVP in Fig. 6, where the AV has an active network connection with other entities, such as users, car park and control centre. We give more details as follows: [53]

1) LAVP Components: In LAVP, the car parks can be deployed in less congested and remote areas, which are usually on the borderline of the city centre. The users can demand to leave the car at several drop-off spots.

Driving Mode: This step involves AV planning and travelling around the city or any other place before delivering the users at the drop-off spot. It may include the selection of car park, parking slot scheduling, routing guidance and congestion avoidance.

Scheduling Centre: In LAVP, scheduling centre has an important role in arranging parking operations and providing an optimized solution towards journey time, fuel consumption and parking fee. All the car parks and drop-off spots are expected to continuously share their status with the scheduling centre.

Request: Once the parking request is approved, the scheduling centre sends out relevant information to AV[8]. The AV then proceeds to the suggested drop-off spot, after which user leaves AV at drop-off spot and starts walking towards the workplace. In the meantime, AV will move towards the selected car park and parking slot autonomously.

Drop-off Spot: The drop-off spot can be selected by the users, which may be in the city centre, near to the users' work space or business hubs as well as the shopping malls.

Pick-up Spot: The pick-up spot can be served by previous drop-off spot, if the users wish to be picked up at the same place for outbound trips. Users can send a certain office time to the scheduling centre (SC) when they wish to be picked up. The SC then schedules AV towards the pick-up spot, by considering time taken by the user to walk from workplace to pick-up spot as the constraint.

2) Features of LAVP:

- **Fuel Cost**: LAVP has the capability of selecting car parks with lower parking fee and guiding the AV through selected routes. Thanks to smart decisions and scheduling policy, comparatively lower congestion rate and less fuel consumption may be achieved via LAVP.
- **Quality of Experience**: The LAVP has the potential to provide users with the best parking experience, as it can drop off the user at their required place and then moves towards the car park in full autonomous mode. This can make the users get rid of some hurdles, e.g., searching for car parks, parking vehicles in narrow slots, and working from car parks to their desired place [17].
- **Environmental Pollution**: In LAVP, LAVP can provide real time solutions for congestion avoidance and with proper scheduling, the vehicle does not have to roam around the city searching for the car park. Therefore, it can help reduce fuel/battery consumption and environmental pollution.
- **Walking Distance**: LAVP can select drop-off locations nearer to their requested place (e.g., workplace) for outbound trip and vice versa and then it also can optimize the walking distance and time consumed in the parking process.
- **Car Park**: The LAVP can broadcast car parks information across the city to users and it can suggest the possible car parks depending on the required drop-off place, walking distance, fuel/battery consumption and parking fees, etc [7].
- **Parking Slot**: Similar to SP, LAVP is expected to park AVs in the designated parking slot in a specified car park with the help of modern computer vision and machine learning related technologies [33].

V. CHALLENGES & FUTURE DIRECTIONS

There are several challenges and open issues in SP and AVP which will be discussed as below.

[8]It includes parking location, floor number (if any), parking fee and the non-congested proper path.

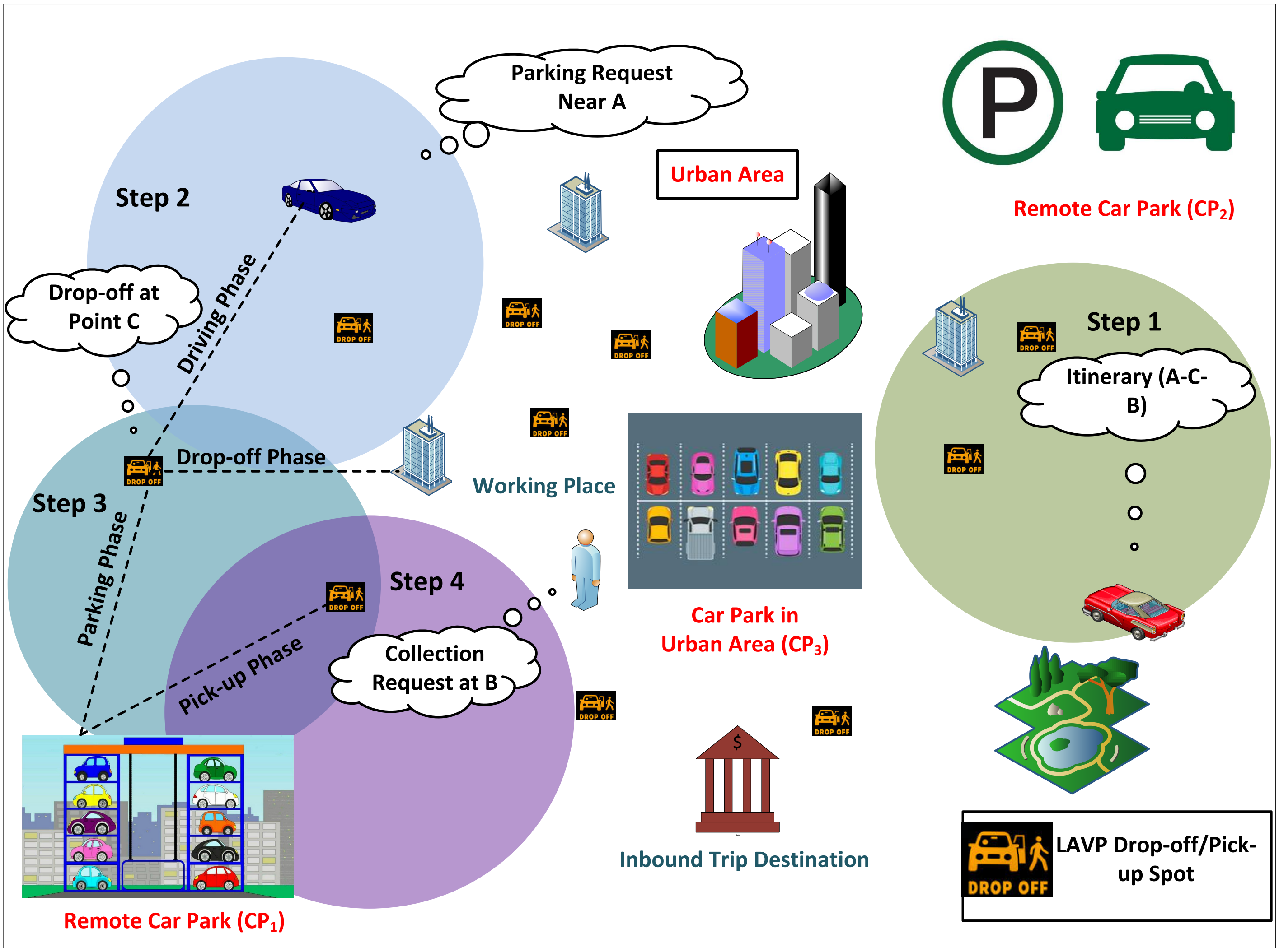

Fig. 6. Broad-view Design for Long-range Autonomous Valet Parking

A. Privacy & Security

Nowadays, data privacy has an increasingly important impact and users start to take a more serious view towards their personal data. More robust and secure algorithms are highly demanded when designing the parking system [24]. Also, the various car theft and misuse issues can be considered [143].

1) Secure Communication: In the parking system, the vehicles are expected to communicate with each other as well as the infrastructure, e.g., Roadside units (RSUs), edge computing nodes and other parking sensors. Some secure communications are expected, e.g., block-chain based algorithms integrated with vehicle communications [144].

2) Data Privacy: Data privacy should be considered in designing data management systems in parking solutions, as the user information may be shared across the networks with other data centres or edge computing nodes. The shared data may include vehicle registration number and users' preferable drop-off locations. Efficient data management is expected to be deployed [145].

B. Congestion Avoidance

Congestion reduction is a challenging task, especially in busy hours. To avoid congestions, several considerations can be made as follows.

1) Path Guidance: The reliable path guidance algorithm can help in maintaining the normal traffic flow, and avoiding congestion by diverting the traffic towards the less busy route, while also considering other constraints, e.g., time and battery capacity. To this end, the shortest path may not always be optimal as other factors e.g., price, infrastructure and traffic congestion may also be considered, depending on the design objective.

2) Utilization of Car Park: The proper utilization of existing car parks without changing other infrastructure is important. Additionally, the new drivers are unable to park in the marked slots and results in wastage of parking space. Therefore, the autonomous mode of parking can be designed. Also, by using HDP, the utilization of parking space can be increased. In the future, some emerging technology, e.g., deep learning, advanced sensing and computer vision may be adopted to help this process.

3) 3D Localization Maps: In most indoor car parks, the global positioning system (GPS) is unable to exactly locate a vacant parking slot. Therefore, the possible application of 3D localization map may be helpful in detecting vacant parking slots and improving the proper utilization of existing parking spaces, especially in multi-story car parks.

C. Deployment

1) Drop-off and Pick-up Spot: Selecting the location of pick-up and drop-off spots can be important. It may consider that the solution does not result in traffic congestion and also convenient for the users to reach their desired getting-off place, as well as other factors like distance and historical traffic condition.

2) Car Park: The possible new car parks can be deployed in remote areas or the border of the city centre to avoid the traffic congestion. The cost, dynamic traffic data and travelling distance can also be considered when selecting the place for the car parks.

D. Scheduling

Allocating a right car park at the right time is beneficial towards increasing users' experience and decreasing other costs, like congestion rate and energy consumption. Next, we discuss several possible solutions.

1) Parking Slot Scheduling: Novel parking slot scheduling algorithm is required, by jointly considering the people's demand and the real-time road information. This is challenging due to the dynamic environment. Some machine learning solutions, e.g. reinforcement learning may be applied.

2) Vehicle Sharing: To further reduce the congestion and increase the users' experience, vehicles can be shared for the people planning to go to the similar or surrounding places. In this case, the matching algorithm can be considered to meet the users' demand in time and spatial dimensions.

3) Charging Scheme: For the EV, the charging scheme is important to maintain the operation of the vehicles [146]. Efficient charging solution is demanded in the scheduling process to support the vehicles, especially in autonomous mode.

E. Green Parking

Green parking is important towards environment protection. Improving the parking search capacity and decreasing travelling time can contribute to the reduction of carbon emission and pollution. Some techniques can be considered, such as applying green energy (e.g., solar power), booking on-line, efficient scheduling and path guidance as well as traffic data analysis.

1) Accessibility: When designing the parking system, one may consider to propose the solutions with easy accessible and reservation, comfortable journey, economical/dynamic prices, trouble-free drop-off and pick-up experience as well as environment-friendly scheduling and planning algorithms.

2) Integrated Parking System: To increase the integration level of different components in parking system may contribute to green parking. For example, one may integrate the built-in GPS, localization maps of multi-story car parks, reservation algorithm, secure payment system and real-time monitoring into the future system. To this end, the novel data fusing technology can be studied which can take all the above-mentioned information into consideration.

3) Digitalized Car Parks: All the car parks can be digitalized with the efficient data management deployed to enable the users to book the journey easily and effectively. In this case, users do not have to drive their own cars. Instead, they can use their mobile device to book the journey including the selection of the drop-off and pick-up spots. With the proper management, the number of cars in the road can be reduced and the green transportation may be realized.

VI. Conclusion

This paper has summarized current parking solutions from traditional parking, towards the smart parking, and then reach the autonomous valet parking schemes. We have provided the taxonomy of SP and AVP, where the SP is divided into DEP, smart routing, high-density parking and parking slot detection mechanisms, while AVP is divided into Short-range AVP and Long-range AVP. In SAVP, users can leave their vehicles at the parking entrance and the vehicle can then park autonomously in a selected parking slot whereas LAVP gives users the opportunity to select a drop-off/pick-up spot away from the car parks. Furthermore, the open issues with future directions have been discussed. Specifically, in the parking system, one may consider the route optimization, high density nature of car parks, reservation system design, data fusion, privacy, dynamic scheduling and environment-friendly algorithms.

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