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***Abstract*—Considering the increase of urban population and traffic congestion, smart parking is always a strategic issue to work on, not only in the research field but also from economic interests. Thanks to information and communication technology evolution, drivers can more efficiently find satisfying parking spaces with smart parking services. The existing and ongoing works on smart parking are complicated and transdisciplinary. While deploying a smart parking system, cities, as well as urban engineers, need to spend a very long time to survey and inspect all the possibilities. Moreover, many varied works involve multiple disciplines, which are closely linked and inseparable. To give a clear overview, we introduce a smart parking ecosystem and propose a comprehensive and thoughtful classification by identifying their functionalities and problematic focuses. We go through the literature over the period of 2000-2016 on parking solutions as they were applied to smart parking development and evolution, and propose three macro-themes: information collection, system deployment, and service dissemination. In each macro-theme, we explain and synthesize the main methodologies used in the existing works and summarize their common goals and visions to solve current parking difficulties. Lastly, we give our engineering insights and show some challenges and open issues. Our survey gives an exhaustive study and a prospect in a multidisciplinary approach. Besides, the main findings of the current state-of-the-art throw out recommendations for future research on smart cities and the Internet architecture.**

***Index Terms*—Smart parking; Sensor development; Driver assistance; System engineering for traffic management systems; Traffic control; Signal systems; Detection systems; Driver behavior; Micro-simulation; Impact Assesment; ADAS; AVCSS; Driver information systems; Data mining; Traffic management; Online application; Driver assistance; Inter-vehicle communications**

I. INTRODUCTION

Parking coordinates land use and transportation in urban areas, and it is also one of the most important assets, bringing revenues to cities. Manville *et al.* [1] surveyed the percentage of total parking areas in the central business district of different cities. Averagely, parking coverage takes 31% of land use in big cities, like San Francisco, and even more, 81% in Los Angeles and 76% in Melbourne, while at the lower end we find New York (18%), London (16%), and Tokyo (7%). Such a super high parking coverage density in Los Angeles can be a constraint on urban redevelopment and lead to an increase of vehicles as well as a reduction of public transportation [2]. Hence, the removal of unnecessary parking areas is the first task for municipalities to create a better urban planning. Understanding and improving the legacy parking search can help achieve this goal, e.g., 98% of automobile trips within the Los Angeles metropolitan area start or end with free parking (California household travel survey, 2013). 100% of Parisian drivers ever abandoned their trips because of annoying and endless parking searches and some drivers park their cars on unauthorized areas (Association for European Transport 2006). Accordingly, if drivers can have real-time parking availability information, they will be able to adjust their traveling schedule without spending time cruising the city in vain. Many cities have started smart parking projects. *Smart parking is a way to help drivers find more efficiently satisfying parking spaces through information and communications technology*, especially for occidental countries. Big American cities, like Los Angeles and San Francisco, have respectively 63% [3] and 75.5% [4] of on-street parking among all the parking spaces, European cities averagely have 37% [5], Beijing [6] only has 5%, and Tokyo has scarce on-street parking. Cities with more on-street parking spaces need comparatively to adopt smart parking to avoid drivers cruising for free parking.

In addition, cities deploy smart parking services on an economic initiative basis. First, drivers can shorten their parking search time, reduce environmental pollution, reduce costs with less fuel consumption and alleviate traffic congestion through information from smart parking apps. That also increases public transportation use rate and cities' revenues as well. Second, if drivers can rapidly find a parking space, the idle time for on-street parking is shorter and the parking revenues increase. Installing sensors on unauthorized areas where people frequently park their car can help detect illegal parking and can issue in a penalty charge, as with electric vehicles and disabled parking stalls. Third, once the traffic is fluent, it increases urban mobility and expands cities' capacities. It brings more population, activities and business opportunities. Evenepoel *et al.* [7] made a study about the on-street parking sensor networks cost model in Ghent and compared the annual reduction in city-wide congestion cost with the annual cost of the entire network. The figures show that all deployments up to 5000 sensor nodes are economically viable. Xerox, involved in a smart parking project in Los Angeles, gives the idea of LEAN SMART PARKING[1] by illustrating the tradeoff between the costs and the benefits from smart parking systems. Thus, smart parking or even smart city deployment is strategically profitable when the system scale is limited and well positioned. Moreover, smart parking deployment intends to deploy many sensors in cities and overcome current sensor management problems. It can become a leading paradigm of smart cities [8].

The goal of this survey is to give a comprehensive guide to the state-of-the-art in smart parking. To the best of our knowledge, there exist five previous efforts in smart parking solutions [9–13]. Idris *et al.* [10] and Revathi *et al.* [9] both did a survey on smart parking systems using different parking sensors and the affiliated functionalities, e.g., centralized or opportunistic information storage systems, park-and-ride facilities, E-parking, automated parking, payment systems, reservation systems, parking assist or guidance systems and vehicle license plate recognition. Polycarpou *et al.* [11] presented a survey on drivers' needs for parking infrastructures, e.g., public parking, drivers' behaviors, parking availability moni-

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[1] www.services.xerox.com/transportation-solutions/resources/parking-management

toring, guidance and information systems, reservation systems, dynamic pricing, and municipal deployments. The authors also emphasized the importance of information dissemination. Delot *et al.* [12] introduced several existing parking information dissemination systems, e.g., crowdsensing, peer-to-peer communication, multi-agent systems, the time-varying traveling salesman problem, gravity-based parking competition, parking meter networks, parking automats, parking information dissemination using roadside units, opportunistically assisted parking searches, mobile storage and reservation. The authors then compared their own protocol with the above. Faheem *et al.* [13] classified the current smart parking systems and explained their features: agent-based for dynamic and complex traffic environment to define the interaction between drivers and parking systems; fuzzy-based for human-like intelligence and expertise; wireless sensor-based for the detection and monitoring of the parking facilities; GPS-based to provide real-time location and guidance systems; vehicular communication for parking information distribution services among mobile vehicles; vision based for lot occupancy detection and space recognition. These surveys gave interesting preliminary studies on some existing smart parking solutions. But none of them gives a so comprehensive classification on all the existing research projects, patents, commercial solutions and municipal deployments.

This article surveys the parking solutions literature over the period 2000-2016 focusing on the development and evolution of smart parking. The contribution of this survey is threefold. First, we study many and varied academic publications, urban development projects and commercial products. We propose an exhaustive classification with an overview of different disciplines. We believe that our survey extends all these works and gives a more comprehensive assortment on the actual development of smart parking. Second, we categorize the smart parking literature and visualize in detailed tables and figures. We synthesize the main methodologies used in the existing works and give a very comparable outlook. Third, we provide our engineering insights on the challenges of the current proposals and the subsequent open issues. Our insights can help cities decide which technology they want to apply and avoid repeating bad try and error processes while deploying a large-scale smart parking system. The work presented in this paper focuses on the methodologies adopted in the vast literature rather than the results. In the same spirit, we give pre-category tables to provide a snapshot of these varied works. We summarize the nature of their works and the research topics they address in the following section according to different functionalities.

II. Overview of the research field

Since smart parking that integrates knowledge from different disciplines seems to be a feasible solution for our cities, sensor and service deployment technology has been maturing through a densification of large-scale deployments all over the word. We sketch the evolution of smart parking in Section II-A and reveal the induced research directions. In Section II-B, we propose a classification of the existing smart parking solutions

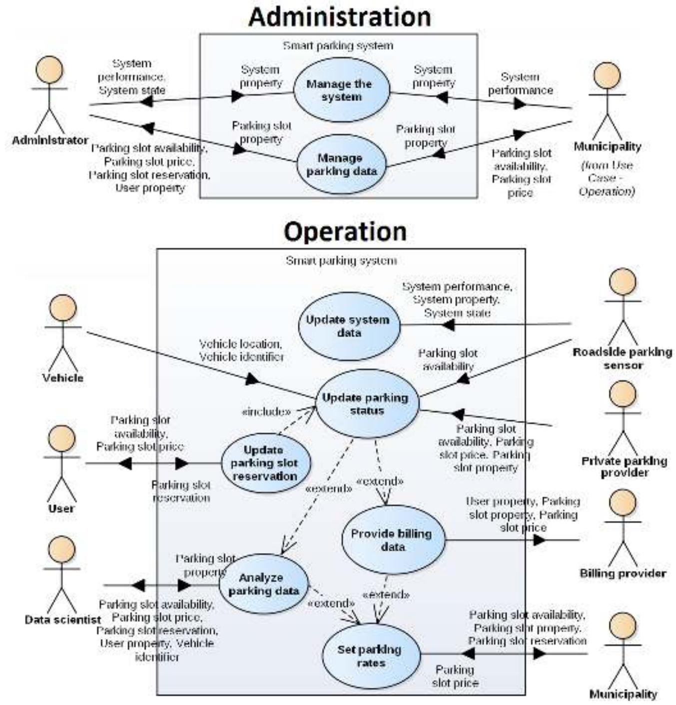

Fig. 1. Smart Parking use case

and explain their corresponding disciplines. Finally, we outline the organization of this survey in Section II-C.

A. *Causes of evolution*

Before going into technical details, we first provide an use case of smart parking service, including eight actors from the administrative and operational viewpoints, in Fig. 1 in which are clearly illustrated how different data sources can support potential services as well as the huge need for parking data acquisition and management. Nowadays, the Internet is turning more and more dynamic, dense and heterogeneous. To support such a real-time service, conventional system architectures cannot satisfy any more drivers. Endless parking conflicts are happening every moment and we have to reconsider the system from all different perspectives, as a smart parking ecosystem.

An essential smart parking ecosystem includes two flows: information and traffic. The traffic flow happens on the pathway to find parking, shown in the azure lower triangle in Fig. 2. Vehicle drivers receive parking availability information, steer to their desired parking areas and then park. When there are many drivers looking for a parking space, a competition occurs and results in cumulative parking conflicts. Parking behaviors also vary considering the information drivers have and how long they are cruising on the street. Once a vehicle arrives in or departs from a parking space, the parking availability information changes and is advertised to other drivers looking for a parking space. The parking information, from the moment when they are detected by sensors to the moment when they appeare on driver's terminals, is called the information flow, shown in the upper pink triangle in Fig. 2. To get the occupancy status of parking spaces, sensors are installed on on-street parking to detect vehicular events. Then,

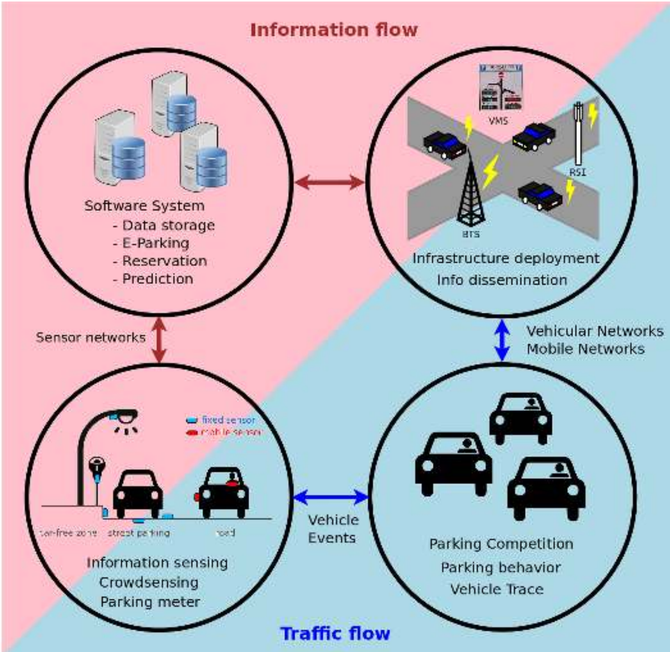

Fig. 2. Smart Parking ecosystem overview

sensors form a network and send the latest information to data storage devices. Drivers can obtain the latest information from variable message signs (VMS) or their handheld smart devices that exchange messages with roadside infrastructure (RSI) or base transceiver stations (BTS).

Although there are many deployment projects and apps, still very few drivers can really benefit from smart parking. SFpark (San Francisco) and LA Express Park (Los Angeles) are two most famous successful stories. But if we tried to deploy the same system in another city, it is always essential to make a preliminary test, choose the most suitable technology and then adjust the system according to the city street layout and inhabitants' habits. Nice is the first French city where a smart parking project was launched. Ten thousand sensors are installed in 13 different parking areas. A smartphone app was developed so that drivers can check parking availability information. Parking sensors are connected to nearby multi-service parking meters. Non-smartphone users can pay their parking spaces, get current parking availability in the city, and obtain tourism or public transportation information simply by multi-service parking meters. The deployment cost is estimated at 15 million euros, but most drivers are not satisfied at all. The initiative of the project is undoubtedly good, but this technology still has to be improved from different perspectives:

- The robustness of sensor devices – Sensor devices are embedded systems that process sensed data into useful information and always evaluate their own health status, i.e., lifetime or malfunction, to inform system administration of any problem.
- The stability and timeliness of sensor networks – The sensed information on sensor devices shall be collected through wireless networks. When there are lots of sensor devices, the spectrum is often limited and a transmission scheduling is needed [14]. When a vehicle parks on a sensor-equipped parking space, it might block the radio communication and the status change will not be broadcasted on time.
- The quality and agility of city service – Smart parking system uses sensed information to offer real-time parking information to drivers. The system has to manage all of the parking resources, maintenance, and payments. It has to efficiently filter parking information through drivers' interests. If the drivers' interests are not well defined, the system shall be able to adapt and still provides a minimal level of service quality.
- The user-centric information dissemination and assignment – Currently all the smart parking apps provide the same information to all drivers, but real-time parking availability data is useful only when the driver is very close to the parking location [15]. Hence, the information shall be broadcasted to drivers considering their mobility and location.
- Uncertainty of drivers' behaviors and traveling traces – Drivers' behaviors are strongly related to the information they have from smart parking systems, personal preferences, and the city street layout. Before getting drivers' data, their behavior can only be obtained from payment information or questionnaires. Thanks to sensors deployment in cities, scientists will be able to analyze the measured data and reproduce them in a large-scale simulation.

Considering all the key factors identified above, research on smart parking appears promising and beneficial to cities' sustainable development. The survey summarizing existing works will evolve into a useful engineering guideline in this transdisciplinary domain.

B. Literature classification

Smart parking solutions literature is very diversified. Harmonizing the relevant works in transdisciplinarity is not trivial. We ultimately decide to categorize them by their functionalities. The general outline of the proposed classification is in Fig. 3. At the top level, we identify three macro-themes according to the goals of the research fields: they manage information collection, system deployment, and service dissemination. Within each macro-theme, a tree of sub-topics is germinated and developed. Next, we give an overview of the three macro-themes with all the topics named in our classification.

Information collection takes a technical overview of all the existing sensing techniques to identify parking spaces status. Two major research focuses are on the identification and transmission of vehicular information. The former involves various stationary and mobile sensors, including their detection methods and installation. The latter explains how sensors and cities' infrastructures collaborate together to gather information efficiently. We introduce two emerging urban services, i.e., crowdsensing and gaparking, applied in smart parking. Both of them consider citizens as parking detectors that contribute to accessible parking information on the Internet.

System deployment deals with the software system exploitation and the statistical analysis of the collected data.

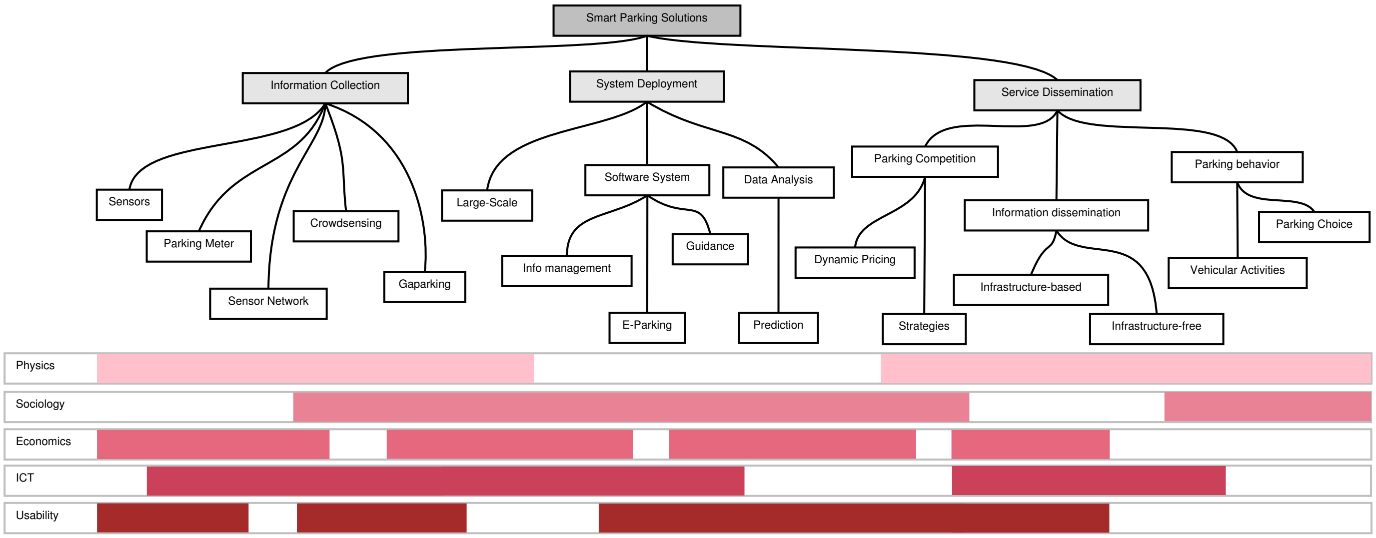

Fig. 3. Proposed categories of smart parking solutions and the spectrum of disciplines related to topics. (ICT: information and communications technology.)

Software generally involves E-Parking, reservation, guidance and monitoring information for administration and users. With the collected data, an analysis is often performed by data scientists to study drivers' behaviors so as to improve the system performance and help municipalities make a better urban planning.

Service dissemination investigates the relationship between information and social features. Two major research focuses are information dissemination and parking competition caused by individual behavior. Information dissemination is mainly related to communication techniques between vehicles and information. Municipalities can choose where and how to install urban infrastructure according to their planning and budget. Parking competition always happens when more than two drivers contend the same parking space. With the information assisted smart parking service, drivers' decisions are even more complicated to predict. Thus, studies on parking behaviors are important while designing a smart parking system.

The classification in Fig. 3 shows that all the sub-themes involve at least two disciplines by their nature. We can remark that smart parking research highly contributes on different inter-disciplines and attracts a variety of participation on urban development.

C. Survey organization

As previously mentioned, we introduce smart parking solution on three different themes. We first start by explaining how to obtain parking information from different networked sensors in Section III. Information collection is an important step to visualize vehicle's activities. It is also a converter between traffic and information flows. We discuss all the different sensors in Section III-A and the required network to gather their sensed information in Section III-B. Parking meters are often the most important component of user interfaces. We also introduce some parking meters patents in Section III-C. For companies or academic projects, large-scale sensor networks deployment is costly. Hence, we introduce the crowdsensing method used in smart parking applications in Section III-D. Next, in Section III-E, we present the gaparking, voluntarily sponsored by parking owners, which does take advantage of idle parking resources. Then, we present a way to deploy a smart parking service system considering different service types, e.g., payment, monitoring, reservation, guidance, and information presentation, in Section IV. We start by studying the software system in Section IV-A. Drivers cannot only be guided or advised by smart parking system but also reserve or pay their parking spaces through the Internet. Then, we investigate the existing large-scale deployment projects and compare them with the technologies mentioned in Section III to examine how cities adopt their smart parking solutions IV-B. To provide good quality of information and even to apply a better parking policy, data analysis is often a must, as well as information aggregation and prediction. Section IV-C presents some forecasting methods used in the current literature.

After that, we discuss how to spread information and the side effects in Section V. The approach evoked in this section often imply a social analysis since human activities are often difficult to precisely capture and estimate in complicated real life with ambiguous information. Information dissemination is the first key point to influence traffic flow by an information system. In Section V-A, we show different information spreading ways according to cities' infrastructures and sensor transceiver modules. Drivers' mobility is also affected by the new information-assisted parking search. There are two major research themes, on the one hand, parking occupancy improvement and drivers' satisfaction, and on the other hand, parking competition and drivers' behaviors. We present the current works on parking competitions in Section V-B. Some methods are proposed to ease drivers' conflicts. Section V-B is often linked with historical data mentioned in Section IV-C depending on whether drivers have complete or incomplete information of the system. Later, in Section V-C, we show some works on drivers' parking behaviors. Finally, we give a general overview of the three different themes and conclude our work in Section VI. We also provide our insights and some perspectives on our contributions and the vast literature.

III. Parking information collection

Here, we introduce different sensors and the ways to deploy them, then we present some works on the sensors and parking meters networks. Additionally, we reveal the crowdsensing detection manner. More and more parking apps try to gather parking information without deploying thousands of sensors in urban areas. Except for municipal and academic projects, we also present gaparking services proposed by individual parking owners. We organized the literature related to information collection in Table I. Information sensing lists all the sensor designs applied to smart parking system. Most of them transmit sensed information via 802.15.4 for its rapid installation without any subscription to mobile operators. WSN extends sensor designs works but mainly on network protocols and network performance (sensor lifetime and latency) of short-range communication networks. Crowdsensing focuses on the app development for smartphone users to ensure parking information and location accuracy. Long-range communication networks, parking meters, and gaparking are not dedicated to this table. Even though they are flourishing on the market, we do not find any academic publication.

A. Information sensing

Information sensing relies on sensors to collect real-time parking availability information. Stationary and mobile collection are two types of methods. The former instinctively adds sensing ability on parking spaces. When the occupancy status changes, a sensor can detect a vehicle's presence or absence and updates the information in a short time, e.g., SFpark [4], in San Francisco, allows that 85% of events are received within 60 seconds on large-scale roadside parking sensor networks. The latter takes advantage of the vehicle's mobility to collect information along the route with fewer sensors. Mobile sensors can detect the occupancy status when they pass through a parking space, so the information might not be updated for a long while, e.g., ParkNet [57–59], also in San Francisco. In ParkNet, taxi cabs collect data from GPS receivers and ultrasonic sensors and then transmit it over a cellular uplink to the central server. Such a mobile parking sensor system requires much less installation, yet needs a longer average inter-polling time, to wit, 25 minutes for 80% of the cells in the business downtown area with 300 cabs. Several potential positions to install sensors are shown in the bottom left circle in Fig. 2. Different sensors have distinct manners to detect a vehicle's presence. Table II gives a general idea of different types of sensors, and we explain them in detail as below.

Passive infrared sensors receive heat radiated from the human body and are often used collaboratively with other sensors [17, 18] to know if a driver parks and gets off his/her car. Active infrared sensors measure the distance to any obstacle in front [30, 32, 34, 60–62]. Infrared sensors are very sensitive to sun and any kind of environmental object so that the sensing accuracy is not so good. Similar to infrared sensors, ultrasonic sensors use sound instead of light and work better in outdoor environments. Ultrasonic sensors provide a more complex signal pattern with a possibility of multiple detections in fixed [24, 32, 63] or mobile [55, 58, 64] scenarios. Accelerators measure the instantaneous ground vibrations. Since vehicles are usually the heaviest objects on the street, accelerators can infer that a vehicle comes and parks, with the aid of other sensors, e.g., optical sensors [65], which detect the change in light. Optical sensors must be installed where light can be obscured by a parked vehicle [25, 32, 66–69]. However, optical sensors are vulnerable to any light source and transient staying objects, so their accuracy is still questionable. Magnetometers are, so far, the most common stationary parking detection sensors, especially for municipal deployment [3, 4, 6, 67, 70–73]. It measures the current magnetic fields and detects huge metal objects presence. Its signal pattern is easy to read and precise but cannot support multiple detections. It is also more expensive than the above-mentioned sensors. Alternatively, [26] installed magnetometers along the driving pathway and compared the different counts between any two adjacent sensors to know roughly how many vehicles are parked between them.

Cameras [16, 27–29, 74, 75] and acoustic sensors [31, 32] provide a much more complicated signal pattern than ultrasonic. Both of them require image and sonar processing in order to extract the desired information from the background noise. Nevertheless, they have aroused certain research interests because of some extra information, concerning criminal scenes or personal privacy. Inductive loops and piezoelectric sensors are both contactive and installed on road surface. Inductive loop technology is considered mature, and is widely used for traffic surveillance. It simply detects if a vehicle is passing [24, 76]. Piezoelectric sensors are similar to inductive loops but able to read more detailed information from the pressure exerted on it [77]. Such kind of contact sensors require an intrusive installation and they are easy to be worn-out because of their frequent use. RFID is often proposed in smart parking payment solutions thanks to its identification tag. As the popularity of electronic toll collection (ETC) increases, many vehicles, equipped with RFID tags, can be detected by RFID readers installed on parking spaces [21, 23, 35, 36]. Laser rangefinder is often used to build a 1/2/3D map, especially for environmental perception. Normally installed on vehicles, it emits a laser beam and calculates the time of flight to measure the distances from different objects in order to know if there are parked vehicles [78]. Intelligent robots cruising on the street can also be used to recognize available parking spaces [79].

Mobile crowdsensing via smartphone is the most economical way to obtain parking availability information from drivers themselves [49, 51]. However, it yields privacy issues if smartphones automatically collects data from users according to their movements [44, 52, 80], Bluetooth connection [81], WiFi signatures [41], 3D compass [43] or all of them [42], and then updates in a public database. If users can choose to contribute information on mobile applications, the system will be sensitive to free-riders [50] and selfish liars [54, 82, 83]. QR codes might be installed on parking spaces to help drivers

TABLE I
SMART PARKING SOLUTION FOR INFORMATION COLLECTION

	Reference	Info source		Deployment		Storage			Service				Parking game			Network	
		Type	S/P	NetS	NetU	C	D:s/v	D:I	AU	BC	EP	Rsv	UB	SG	PD	NP	OT
Information sensing	B. Zhang [16]	5	1/6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	U-Park [17]	1^p,3	2/2	802.15.4	-	-	-	-	-	-	-	-	-	-	-	-	-
	Männi [18]	1^p,3	-	802.15.4	-	-	-	-	-	-	√	√	-	-	-	-	-
	Z. Zhang [19, 20]	3	82/82	802.15.4	-	√	-	-	-	VMS	-	-	-	-	-	-	-
	Abdullah [21]	10	-	802.15.4	-	√	-	-	-	VMS	-	-	-	-	-	-	LT
	PGS [22]	3	*/10	802.15.4	-	√	-	-	Pois(1)	VMS	-	-	-	-	-	√	LT
	W. Zhao [23]	3,10	(40/40)·2	802.15.4	Wifi,CN	√	-	-	-	VMS	-	-	-	-	-	√	-
	Kianpisheh [24]	4,8	100/100	CB	-	√	-	-	-	VMS	-	√	-	-	-	-	-
	Chinrungrueng [25]	7	2/1	WSN	Wifi,CN	√	-	-	-	-	-	-	-	-	-	-	-
	Boda [26]	3	11/72	-	-	√	-	-	171-183	-	-	-	-	-	-	-	-
	Sevillano [27]	5	-	-	-	-	-	-	-	-	-	-	-	-	√	-	-
	Nguyen [28]	5	-	-	-	√	-	-	$\leq$5K	-	-	-	-	-	√	-	-
	COINS [29]	5	-	cable	-	√	-	-	-	VMS	-	-	-	-	-	-	-
	SmartSpaces [30]	1^a,3,4	*/36	RF,Wifi	-	√	-	-	-	-	-	-	-	-	-	-	-
	Na [31]	5,6	35/35	802.15.4	-	√	-	-	-	-	-	-	-	-	-	-	-
	Lee [32]	1^a-7	-	802.15.4	-	-	-	-	-	-	-	-	-	-	-	-	LQ
WSN	Benson [33]	3	5/5	nRF24L01	-	√	-	-	-	-	-	-	-	-	-	√	LQ
	Urdiain [34]	1^a	10/10	nRF24L01	-	√	-	-	-	-	-	-	-	-	-	√	-
	Bagula [35, 36]	4,10	13/*	Zigbee,CB	-	√	-	-	-	VMS	-	√	-	-	-	√	-
	Asaduzzaman [37]	1^a	-	Zigbee	-	-	-	-	-	-	-	-	-	-	-	√	LT
	Lin [14, 38, 39]	3	*/12-120	802.15.4	-	√	-	-	-	-	-	-	-	-	-	√	LT
	W. Chen [40]	3	-	WSN	-	-	-	-	-	-	-	√	-	-	-	√	-
Crowdsensing	ParkSense [41]	14	-	CN	-	√	-	-	-	-	-	-	-	-	-	-	-
	UPDetector [42]	14	-	Wifi,CN	-	-	-	-	-	-	-	-	-	-	-	-	-
	Villanueva [43]	14	-	Wifi,CN	-	-	-	-	-	-	-	-	-	-	-	-	-
	VeLoc [44]	14	4/445	Wifi,CN	-	-	-	-	-	-	-	-	-	-	-	-	-
	Gupte [45]	14	*/480	Wifi,CN		√	-	-	Pois(60)	-	√	-	√	-	-	-	-
	Park Here! [46]	14	-	Wifi,CN		√	√	-	-	VNT	√	-	-	-	-	-	-
	Farkas [47]	14	-	Wifi,CN		√	-	-	5000	-	-	-	√	-	-	-	-
	Krieg [48]	14	-	Wifi,CN		√	-	-	-	-	-	-	-	-	-	-	-
	Rinne [49]	14	*/138 areas	Wifi,CN		√	-	-	-	-	√	-	-	-	-	-	-
	X. Chen [50]	14	*/810	Wifi,CN		-	-	-	1K	-	-	-	√	-	-	-	-
	iPark (Yang) [51]	14	-	Wifi,CN		√	-	-	1G	-	-	-	-	-	-	-	-
	PocketParker [52]	14	105/*	Wifi,CN		√	-	-	-	-	-	-	-	-	√	-	-
	Kifle [53]	14	*/ 6 zones	Wifi,CN		√	-	-	-	-	-	-	-	-	-	-	-
	ParkJam [54]	14	-	Wifi,CN		√	-	-	-	-	√	-	-	-	-	-	-
	Coric [55]	12	-	Wifi,CN		√	-	-	-	-	-	-	-	-	-	-	-
	TruCentive [56]	14	-	Wifi,CN		√	-	-	131	-	√		√	GT	-	-	-

†In the Type column: the type id is referred to Table II.
†In the Info source columns: S/P is the ratio of sensors to parking places.
†In the Deployment columns: NetS is the network of sensors. NetU is network of users (CN: cellular network; CB: cable; BT: bluetooth; PLC: power-line communication).
†In the Storage columns: C is centralized. D is distributed (S/V/I: sensor/vehicle/infrastructure).
†In the Service columns: AU is amount of service users (Pois: poisson - unit: vehicles/minute), BC is broadcast (VMS: variable message sign, VNT: vehicular network), EP is E-Parking (namely drivers can find parking through telephone or the Internet). RSV: reservation.
†In the Parking game columns: UB is user behavior, SG is strategy (GT: game theory).
†In the Network columns: NP is network protocol, OT is others (LT: lifetime; SC: security; AG: aggregation; LQ: link quality; FW: framework; SA: search algorithm).

identify and pay their parking spaces [84]. When a driver ends a parking session, the system will announce that his/her parking space is now available to other drivers looking for parking. However, this system cannot control if drivers do pay their parking spaces since QR codes cannot detect vehicles' presence.

B. Sensor connectivity

Once networked sensors are installed on parking spaces, they can form a network to send out their messages. There are two typical communication methods: either short-range, such as Bluetooth/BLE, 802.11ah (Wi-Fi HaLow) and Zigbee/Z-Wave/DigiMesh, or long-range, like Sigfox, LoRa, Weightless, Ingenu and NB-IoT/LTE-M. The long-range communication benefits from the existing radio access network and can communicate with infrastructures anytime and anywhere. Short-range communication is often implemented by WSN where messages have to be re-transmitted several times via relays, e.g., parking meters or other sensors, until they reach cities' infrastructures. The studies on WSN have been germinating for several years but few of them have been evaluated in an urban parking context considering lifetime, information delay, and wireless link quality constraints.

1) Low-power wide-area network (LPWAN): Considering the rich functionality of 3G/4G is unnecessary for networked sensor devices, a long-range cellular link has to be adapted to the emerging IoT market. Long-range IoT communication technologies, namely cellular IoT, are designed for LPWAN. Because of their compatibility with the existing cellular networks, no extra infrastructure is required. The three most famous standards are SigFox[2], LoRa[3] and Weightless[4]. French SigFox and Weightless SIG both tried to minimize the bandwidth in order to reduce the probability of interference. The narrow band (NB) technology is simple to implement and meets very low energy requirements. SigFox uses ultra narrow

[2]www.sigfox.com
[3]www.lora-alliance.org
[4]www.weightless.org

TABLE II
DIFFERENT TYPES OF PARKING DETECTION SENSORS.

	N^o	Sensors	Intrusive	Flexible	Environmental Impact	Small Size	Privacy	Installation	Contact	Accuracy	Cost	Multiple Detection
Stationary	1^a,1^p	Active^a /passive^p infrared [17, 18, 30, 32, 34, 60–62, 77]		√	√	√		⋆		⋆⋆	⋆	√
	2	Accelerator [65]			√	√		⋆		⋆	⋆	√
	3	Magnetometer [3, 4, 17–19, 22, 23, 26, 30, 32, 70, 71, 85]	√			√		⋆⋆		⋆ ⋆ ⋆	⋆⋆	
	4	Ultrasonic [24, 30, 32, 63]		√	√	√		⋆		⋆ ⋆ ⋆	⋆	√
	5	Camera [16, 27–29, 74, 75, 86]		√	√	√	√	⋆		⋆⋆	⋆ ⋆ ⋆	√
	6	Acoustic [31, 32]		√	√	√	√	⋆		⋆	⋆ ⋆ ⋆	√
	7	Optical [25, 32, 65–69]		√	√	√		⋆		⋆⋆	⋆	
	8	Inductive loop [24, 76]	√					⋆ ⋆ ⋆	√	⋆ ⋆ ⋆	⋆	
	9	Piezoelectric sensor [77]	√		√			⋆ ⋆ ⋆	√	⋆ ⋆ ⋆	⋆ ⋆ ⋆⋆	√
	10	RFID [21, 23, 35, 36], iButton [87]	√	√		√	√	⋆⋆		⋆ ⋆ ⋆	⋆⋆	
	11	Radar [88]		√	√	√		⋆		⋆ ⋆ ⋆	⋆ ⋆ ⋆	√
Mobile	12	Ultrasonic [55, 58, 64]		√	√	√		⋆		⋆ ⋆ ⋆	⋆	√
	13	Laser rangefinder [78]		√	√	√		⋆		⋆ ⋆ ⋆	⋆ ⋆ ⋆	√
	14	Smartphone (GPS, human, microphone, Bluetooth [81], Wifi [41], accelerator [44, 52, 80], magnetometer [43], QR code [84]) [42, 48–51, 54]		√	√	√	√	-		-	-	√
	15	Camera (on robot) [79]		√	√	√	√	⋆		⋆	⋆ ⋆ ⋆⋆	√

band (UNB) technology and RFTDMA (random FDMA and TDMA), an ALHOA-based protocol without medium sensing, associated with UNB to handle transmission schedulings. Each device can only send 140 12-byte messages per day. Thus, it can consume very few energy and achieve a very long communication range (around 10km in urban areas). SigFox cooperates with WorldSensing to provide a long-range wireless connectivity to networked parking sensors. Weightless (formerly British Neul) provides 3 different models: UNB, NB, and DSSS (Direct Sequence Spread Spectrum) named respectively Weightless-N, Weightless-P, and Weightless-W, so as to address different users' needs. Vodafone adopted Weightless as its IoT solution works with Smart Parking Ltd in the UK and Australia to collect real-time parking information. UNB provides a better channel use so that there are much more simultaneous active users per channel than the famous LoRa. LoRa spreads spectrum to have an adaptive data rate. Its sensitivity and throughput are mainly related to bandwidth, coding rates and spreading factors. LoRa targets a wide range of applications but is not very popular yet in smart parking real deployment. A small LoRa equipped pilot project is being tested in Geneva. Libelium[5] has implemented LoRa and Sigfox on their smart parking products.

In addition, Ingenu (formerly) launched an IoT protocol with RPMA (random phase multiple access) technologies based on DSSS that can serve 1000 simultaneous users according to its high spreading factor. We do not yet find existing smart parking solutions of Ingenu. 3GPP is also working on its IoT standards, namely NB-IoT and LTE-M, with NB technology. Many companies, such as Qualcomm, Huawei, Ericsson, and Mediatek are all developing their products on LTE-M.

2) Wireless sensor network (WSN): Unlike LPWAN, WSN does not need a monthly fee per sensor. In order to coordinate a group of sensors, delay, and mesh networks energy efficiency are the main challenge. Urdiain *et al.* [34] tested the LEACH[6] routing protocol on the Arduino platform[7] which is used as the parking sensor. Benson *et al.* [33] used the DSYS25[8] sensing node to experience packet delivery rates with parked vehicles. If either senders or receivers are covered by parked cars, communication reliability in the range of 0 to 5 meters is good. If senders and receivers are both covered by parked cars, no communication is possible. Karbab *et al.* [36] implemented a car park management system and compared energy and cost efficiencies while deploying a WSN and serial connections. Bagula *et al.* [35] formulated the optimal placement of ultrasonic sensors in smart parking as a multi-objective integer linear programming problem. W. Chen *et al.* [40] adopted a smart energy-efficient sensor. While increasing the number of sensor nodes, the authors showed that smart sensors can consume less energy in a larger network scale. Asaduzzaman *et al.* [37] proposed an ARM-based sensor node equipped with Zigbee, Bluetooth or WiFi and compared their corresponding transmission time and energy consumption. The results showed that Zigbee is the best choice in terms of sensor lifetime and maximum connected nodes in mesh networks. Lin *et al.* [39] also formulated cities' infrastructures optimal placements as a multiple-objective problem and solved it in real maps. Besides, four different MAC protocols in street parking scenarios are implemented to compare the performance evaluation of schedule, contention-based and hybrid bandwidth allocation methods [14, 38].

[5]www.libelium.com/smart-parking-surface-sensor-lorawan-sigfox-lora-868-900-915-mhz/

[6]nms.lcs.mit.edu/projects/leach

[7]www.arduino.cc

[8]www.ucc.ie/en/media/research/misl/2004publications/sensys04barroso.pdf

C. Parking meter

An important element seldom studied in smart parking research is parking meters. Yet, there are many companies working on the patents of parking meters for payments, e.g., PhotoViolationMeter™ Solution [89] and IPS group [90]. Parking meters are used by municipalities as a tool to pay on-street parking. With the rise of networked sensors, parking meters are turned into parking helpers, which establish a link between drivers and parking data. Single-space and multi-space meters are the two main automated payment machines. Multi-space meter manages several parking meters and can provide more functionalities than single-space ones. Thanks to WSN technology, introduced in Section III-B, parking meters are often used as relays for parking sensors. Thus, parking meters are not only basic payment machines but also transceivers, which can be integrated into existing relays and infrastructures for any communication devices [91]. Duncan Solutions [92, 93] has patents on parking meters' wireless communications and control system. Parking meters might communicate with some mobile access points, such as taxis and buses, to enrich urban information and increase transmission opportunities [94]. Flextronics [95] has a patent on proposing a parking space finder in a vehicular environment. Vehicular on-board units (OBU) can communicate with roadside parking meters in order to gather availability parking information and find a parking space. IPS group draws a lot of attention because of the famous smart parking project SFpark [4]. Drivers, who park their cars on on-street parking spaces, can easily extend their parking time and pay from the Internet. The payment information will be updated and showed on parking meters [96]. Besides, parking meters have an internal clock and are able to turn off themselves during parking time so as to reduce energy consumption. Some big companies work on service integration to enrich parking meters' functionalities and their interaction with drivers, e.g., Xerox PARC [97].

D. Crowdsensing

Crowdsourcing has been used in some smart parking applications, especially in gathering the sensed available parking information from smartphone users. Thus, a new term *crowdsensing* is then proposed. The most common way is to design a smart parking app and motivate users to voluntarily share information, namely *participatory crowdsensing*, e.g., ParkJam [54]. Rinne *et al.* [49] presented the pros and cons of mobile crowdsensing. Three high-level conclusions can be drawn by mobile sensors: if there was still space in the area, if the area is full, or if the area should no longer be full. Farkas [47] simulated crowdsensing activities for urban parking by using the MASON multi-agent simulation toolkit and displayed the results on OpenStreetMap. Five different spaces were determined to generate individuals' behaviors, such as parking time and probability. Drivers who are not participating in crowdsensing and not using the decision support application, would still benefit from this application. The best result was achieved from the Novi Sad simulation scenario with 5000 agents and 30% crowd-sensor participation, i.e. when 1500 drivers were sensing and sharing parking related events and enjoying the benefits of 14% shorter cruising times.

PhonePark [81] and Park Here! [46] both proposed a parking/unparking algorithm assisted by accelerometers, gyroscope sensors, and Bluetooth. With the aid of Bluetooth, users' transportation mode becomes easier to be detected. VeLoc [44] used smartphones' accelerometer, gyroscope sensors, and the inertial data of pre-loaded maps in order to find a parking space. PocketParker [52] detected users' movements and derived the parking or unparking status by the accelerometer and GPS. ParkSense [41] detected the WiFi beacons to induct if the driver is back to the car or if he/she is moving. UPDetector [42] (unparking/parking detector) detected drivers' behaviors according to many different sensors on their smartphone: accelerometer, Bluetooth, microphone, gyro, GSP, WiFi, parking payment app, or users' manual input. Villanueva *et al.* [43] introduced a vehicle detection method using the 3D compass of drivers' smartphone. Thus, smartphones can detect if drivers are parking and if there is any adjacent parked vehicle. Also, the 3D compass can sense available parking spaces in its vicinity. Krieg *et al.* [48] used all the available sensors on a smartphone in order to detect users' transportation mode. The authors proposed an algorithm to indicate 9 different transportation modes, i.e., bicycle, bus, car, pedestrian, subway, motorbike, train, tram and airplane, and then compared with five existing algorithms. The results can be used in smart parking application to know if users are parking or unparking.

X. Chen *et al.* [50] showed that crowdsourcing-based smart parking applications can induce the following problems: information accuracy, participation rates, and freeriders. Gupte *et al.* [45] took users' reputation scores into account in order to evaluate data's reliability. Reputation scores increase each time a device sends non-corrupt data. TruCentive [56] is another crowdsourcing smart parking app. The authors implemented a game-theoretical framework that dynamically adjusts a bonus according to the fraction of honest players. Kifle *et al.* [53] proposed a crowdsourcing smart parking application UW-ParkAssist working with UW-Police. UW-Police provides expert data from the police department and can override incorrect data in UW-ParkAssist to reinforce the collected information reliability.

Accordingly, to avoid uncertain artificial factors, *opportunistic crowdsensing* is an alternative without user intervention. Coric *et al.* [55] use an ultrasonic sensor to collect street parking map, like ParkNet [57–59]. iPark (Yang *et al.*) [51] built a parking map from vehicular trajectories without real-time occupancy status.

E. Shared parking - Gaparking

Gaparking takes the ideas of *gap* and *parking* to share one parking spot to more than one motorist at a different time. Principally, parking spot owners register their spare parking spots on a website through an app with proposed price and service time, and then drivers bid one appropriate space that meets their needs. Some commercial car parks might join to sell their parking spots as a single person. ParkingAuction, Mobypark, and JustPark are the most popular gaparking apps. We also find many local websites specializing in specific cities, e.g., sharedParking and Copark. Gaparking inherits the business model of Uberisation (shared economy) which allows peer-to-peer transactions between individuals' needs and services. It provides adequate parking and reduces excessive land use by optimizing personal resources. Moreover, it fosters area development and citizens connections. To match the parking needs and spaces, Griggs *et al.* [98] proposed a private and randomized algorithm to allocate parking more efficiently and respect the QoS constraints.

IV. Parking system deployment

System deployment is the main task of service providers. The essential element of smart parking system is the software that deals with all the E-parking service and data management. User interface and information processing shall be adapted to the service type. Then a large-scale evaluation shall be done to evaluate service flexibility and scalability. Once the system is running in urban areas, information shall be stored and analyzed to improve its performance and make a better urban

TABLE III
SMART PARKING SOLUTION FOR SYSTEM DEPLOYMENT

	Reference	Info source		Deployment		Storage			Service				Parking game			Network	
		Type	S/P	NetS	NetU	C	D: $\frac{s}{v}$	D:I	AU	BC	EP	Rsv	UB	SG	PD	NP	OT
Software system	Vishnubhotla [63]	4	6/6	Zigbee,CB	-	√	-	-	-	-	√	-	-	-	-	-	-
	Tang [68]	7	80/80	802.15.4	-	√	-	-	-	-	√	-	-	-	-	-	-
	BeeParking [87]	10	24/14	BT,CB	-	√	-	-	24	VMS	√	-	√	-	-	-	-
	Gopalan [99]	fixed	-	Zigbee,CN	-	√	-	-	-	-	√	√	-	-	-	-	FW
	KATHODIGOS [100, 101]	3,5	2/unslotted	CB,WSN	-	√	-	-	-	-	√	-	-	-	-	√	LT
	Jeffrey [69]	7	-	Zigbee	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	LT
	SensCity [102, 103]	3	-	WSN,GSM	Wifi,CN	√	-	-	-	-	√	-	-	MAS	-	-	-
	Yang [104]	7	-	802.15.4,Wifi	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	Calipso [105]	3	5/5	802.15.4	Wifi,CN	√	-	-	-	VMS	√	-	-	-	-	-	-
	Grazioli [106]	-	-	-	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	Souissi [107]	3	5/5	Zigbee	Wifi,CN	√	-	-	-	-	√	√	-	-	-	-	-
	Rico [108]	10	-	802.15.4	WiFi,CN	√	-	-	-	-	√	√	-	-	-	-	FW
	Suryady [109]	3	-	Zigbee	WiFi,CN	√	-	-	-	-	√	√	-	-	-	-	-
	Kumar [110]	1^{a}	4/4	Zigbee	Wifi,CN	√	-	-	2	-	√	√	-	-	-	-	-
	Pazos [111]	3,5	-	802.15.4	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	FW
	Mainetti [112]	7,10	-	6LoWPAN	Wifi,CN,NFC	√	-	√	-	-	√	√	-	-	-	√	-
	iParking [113]	3	2/80-90	RS232&485	Wifi,CN	√	-	-	$\geq$120	-	√	√	√	-	-	-	FW
	Venkateswaran [61]	1^{a}	-	RS232	Wifi,CN	√	-	-	-	-	√	√	-	-	-	-	SC
	Ganchev [114, 115]	fixed	*/2000	-	Wifi,CN	√	-	√	2000	-	√	√	-	MAS	-	-	SC
	Pham [116]	10	*/400	CB	CN	√	-	-	Pois(15,20)	-	√	√	-	MC	-	-	-
	Inaba [117]	-	-	-	CN	√	-	-	-	-	√	√	-	-	-	-	SC
	Giuffre [8, 118]	fixed	*/30-150	-	Wifi,CN	√	-	-	10-80	-	√	√	-	-	-	-	-
	PSOS [119]	-	-	-	Wifi,CN	√	-	-	-	-	√	√	-	-	-	-	FW
	Niculescu [120]	-	-	-	Wifi,CN	√	-	-	-	-	√	√	-	-	-	-	-
	ParkinGain [121]	-	-	-	-	√	-	-	-	-	√	√	-	-	-	-	-
	Yao [122]	4	314/314	CB	-	√	-	-	-	VMS	-	-	-	-	-	-	-
	Bechini [84]	14	-	Wifi,CN		√	-	-	-	-	√	√	-	-	-	-	-
	parkITsmart [123]	14	*/100	Wifi,CN		√	-	-	5,10	-	√	-	-	-	-	-	FW
	Rodier [124]	fixed	6/6	WSN	Wifi,CN	√	-	-	-	VMS	√	√	√	-	-	-	-
	Ducreux [125]	3	-	WSN	CN	√	-	-	-	-	√	-	-	-	-	-	FW
	SmartParking [77]	1^{a},9	*/100-2800	Wifi	802.11	√	√		Pois(20)	VNT	√	√	-	MC	√	-	SC
	Hong [86]	1^{a}	64/64	CB	-	√	-	-	Pois(λ)	-	-	-	-	MC	-	-	-
	Xerox PARC [97]	-	-	-	Wifi,CN	√	-	√	-	-	√	√	-	-	-	-	-
	Jun [126]	-	-	-	-	√	-	-	-	VMS	√	√	-	-	√	-	FW
	SPARK (Srikanth) [127]	3,4	*/20	Zigbee	GSM	√	-	-	3	VMS	√	√	-	-	-	-	-
	Shin [128]	-	*/3500	-	-	√	-	-	120K	-	√	√	√	UF	-	-	-
Large-scale	ParkNet [57–59]	12	50-2000/2.8e5	Wifi,CN	-	√	-	-	-	-	-	-	-	-	-	-	-
	Beijing [6]	3	*/20000	433MHz	-	√	-	-	-	-	-	-	-	-	-	-	-
	SFpark [4, 129]	3	11900/8200	WSN	Wifi,CN	√	-	-	-	-	√	-	-	DP	√	-	-
	LA ExpressPark [3, 85]	3	*/6300	WSN	Wifi,CN	√	-	-	-	-	√	-	-	MC,DP	√	-	-
	Àrea Verda [67]	3,7	*/50000	WSN	Wifi,CN	√	-	-	-		√	-	-	-	-	-	-
	Nice Park [71]	3	*/10000	Zigbee	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	WSN-DPCM [66]	7	25/15	Zigbee	Wifi,CN	√	-	-	-	-	√	√	-	-	-	-	-
	Optimod'Lyon [130]	11	*/30	802.15.4	Wifi,CN	√	-	√	-	-	√	-	√	-	√	-	-
	SmartSantander [72]	3	400/400	Digimesh	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	SIMERT Loja [131]	3	3948/1974	Digimesh	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	Moscow Fastprk [70]	3	*/50000	Sigfox	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	Smart Canton [132]	3,4	16/*	LoRa	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	ParkRight London [60]	1^{a}	3400/3400	Weightless	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
	Melbourne [73, 133]	3	7114/7114	Weightless	Wifi,CN	√	-	-	-	-	√	-	-	-	-	-	-
Predication	Pullola [134]	fixed	-	-	GPS	√	-	-	Pois(λ)		√	-	-	-	√	-	-
	Klappenecker [135]	fixed	*/1000	-	802.11	-	√	√	Pois(19.6)	-	-	-	-	MC	√	-	-
	Richter [136]	3	*/6215	WSN	Wifi,CN	√	-	-	-	-	-	-	-	-	√	-	-
	Vlahogianni [137, 138]	3	253/253	802.15,4	Wifi,CN	√	-	-	-	-	√	-	√	-	√	-	-
	Zheng [139]	3	*/8200+7114	-	-	√	-	-	-	-	-	-	-	-	√	-	-
	E. Wu [140]	-	*/260 lots	-	-	√	-	-	-	-	-	-	-	-	√	-	-
	Rajabioun [15, 141]	-	*/1000	-	CN(4G)	√	-	-	-	-	√	-	-	-	√	-	-
	Ji [142]	-	*/492	-	-	√	-	-	-	-	-	-	-	-	√	-	-
	David (Mobinet) [76]	8	*/2750	-	-	√	-	-	-	-	-	-	-	-	√	-	-
	Y. Wu [143]	-	-	-	-	√	-	-	-	-	-	-	-	-	√	-	-
	Demisch [144]	3	*/8200	WSN	Wifi,CN	√	-	-	-	-	-	-	-	-	√	-	-
	Koster [80]	14	-	Wifi,CN		√	-	-	-	-	√	-	√	MC	√	-	-
	Citypark Bordeaux [145]	-	-	-	Wifi,CN	√	-	√	-	-	√	-	√	-	√	-	-

†In the Type column: the type id is referred to Table II.
†In the Info source columns: S/P is the ratio of sensors to parking places.
†In the Deployment columns: NetS is the network of sensors. NetU is network of users (CN: cellular network; CB: cable; BT: bluetooth; PLC: power-line communication).
†In the Storage columns: C is centralized. D is distributed (S/V/I: sensor/vehicle/infrastructure).
†In the Service columns: AU is amount of service users (Pois: poisson - unit: vehicles/minute), BC is broadcast (VMS: variable message sign, VNT: vehicular network), EP is E-Parking (namely drivers can find parking through telephone or internet). RSV: reservation.
†In the Parking game columns: UB is user behavior, SG is strategy (MC: Markov chain; MAS: multi-agent system; DP: dynamic pricing; UF: utility function). PD is prediction.
†In the Network columns: NP is network protocol, OT is others (LT: lifetime; SC: security; AG: aggregation; LQ: link quality; FW: framework; SA: search algorithm).

plan. Thus, we divide the parking system deployment into three parts and give an outline in Table III. Software system takes a huge part of the literature and manages information management and e-parking services. All of them suppose a centralized server is used to execute the service. Moreover, we also present some works on software package solutions and user interface. Large-scale deployments introduce existing projects including software system and sensor deployments. Unlike other literature, large-scale deployments adopt both short and long-range communication methods and their sensors choice is quite consistent. Prediction is mainly related from data analysis, which gains more and more attention thanks to large-scale deployments and parking meters extension. By some improved machine learning algorithms, drivers can benefit from studied data and know in advance if they have a chance to park their car at a certain time for a certain space.

A. Software system

1) Information management: Software systems are the interface between information and system users. We notice that there are many works on software systems because the interoperability of different systems is tough to handle. Several works began with building a software system for WSN-based smart parking systems. WSN provides detected information to smart parking systems and shall be well managed in order to reply drivers' parking requests. Thus, the first priority is a parking system to monitor and to process data. Jeffrey *et al.* [69] proposed a WSN-based park system not only to monitor the occupancy status but also sensor motes health situation. Drivers can get the billing information via SMS. Vishnubhotla *et al.* [63] introduced a parking vacancy monitoring system with a ZigBee[9]-based WSN to show the parking status in the entrance. Tang *et al.* [68] designed a parking detection demonstration system with a IEEE 802.15.4[10]-based mesh network. Each parking space is equipped with a light sensor to detect a car's presence in order to provide real-time occupancy information. Yang *et al.* [104] designed a WSN-based smart parking system that collects information totally wirelessly. User interfaces are developed on smartphones, a central web-server, and embedded web servers to guide users where available parking spaces are. SensCity [102, 103] implemented a Machine-to-Machine (M2M) architecture including parking sensors and parking applications. To improve smart parking system intelligence, a Multi-Agent System is used and modeled in MOISE[11]. iParking [113] is a smart parking system that collects sensing information and then shows the current occupancy status through a social network, Twitter. KATHODIGOS [100] proposed a central parking information system integrating two different heterogeneous sensor networks, namely wireless networked magnetometers and wired cameras. Then the authors tried to improve the precision of the information by using a fuzzy inference system [101]. Mainetti *et al.* [112] also worked on heterogeneous sensor networks, including light sensors and RFID. The authors introduced a smart parking system with heterogeneous sensor networks, smart IoT gateway, a cloud platform and two different user interfaces, i.e., DriverApp and TrafficApp. RESTful communication is used to exchange information between IoT smart gateway, Apps and the cloud platform. Calipso [105] is a European FP7 project targeting the development of IP connected smart objects. It proposed an architecture including several low-power IP stacks for protocol optimizations. Some authors might propose a wire sensor network due to the bad link quality of low-power wireless communications. Yao *et al.* [122] used CAN bus to connect all ultrasonic parking sensors and then provided a guidance service by an outer screen and light indicators. SmartParking [77] addressed a software and hardware architecture for their smart parking service. Also, a birth-death stochastic process is modeled to predict the revenues and pricing plans. Hong *et al.* [86] proposed a parking emulation platform for those who want to test their parking service with deployed sensors.

2) E-Parking service: Once the data storage and information monitoring are done, cities can provide urban services by using the data they own. Since drivers can get the parking information in advance, a reservation system is often recommended. Kumar *et al.* [110] also presented a Zigbee-based smart parking system that provides parking monitoring, guidance, and parking reservation. Inaba *et al.* [117] introduced a smart parking prototype system supported by the Japanese telephone operator NTT. Telephone users can easily find a parking space and make a reservation by using the Internet. Rico *et al.* [108] designed a smart parking system with different technologies. The system provided a reservation scheme and presented the process while coping with parking requests. Venkateswaran *et al.* [61] proposed a smart parking reservation system that assists drivers when they verify the current parking occupancy status and provides an anti-theft barrier gate with user authentication check. Giuffre *et al.* [8] presented an intelligent parking assistance architecture that targets current parking management solutions through a wireless sensing technology. Withthe example of smart parking, the mobility quality in urban areas is improved. To improve smart parking system efficiency, some works proposed a method or platform to improve the system agility. Ganchev *et al.* [114] presented a parking locator service based on a multi-agent system. Infostations are used to relay the information between a central server and user-end mobile devices. ParkinGain [121] presents the concept of a smart parking application that helps drivers find and reserve parking spaces using their OBUs or smartphones. Since smart parking technologies deploying cost is not negligible, other value-added services can benefit from smart parking technologies to create business opportunities. Bechini *et al.* [84] suggested to install QR codes on parking spaces. Drivers can scan the QR codes in order to pay their parking spaces. When a driver ends a parking session, the system will announce that the parking space is from this moment on available to drivers looking for parking. The authors then studied the relationship between drivers' parking requests and parking spaces' current statuses. A full process from parking search, reservation, occupation, payment, and

[9]www.zigbee.org
[10]www.ieee802.org/15/pub/TG4.html
[11]moise.sourceforge.net

release is discussed from drivers', administrators', and data scientists' point of views. This system is low-cost, but it cannot control if drivers do pay their parking spaces since QR codes cannot detect the presence of vehicles.

3) Software solution: If the collected parking information is massive and intensively distributed, a reliable and scalable software will be required to deploy on servers in order to deal efficiently with all simultaneous drivers' parking requests. Gopalan *et al.* [99] introduced an OSGi[12]-based middleware with a Java-based standard Knopflerfish for smart parking systems. The authors showed that OSGi helps having efficient daily communication, data storage, and processing so that a bundle of services for a parking area can be supported by the database containing all the available parking spaces information. Except for OSGi, cloud on big data features are also very promising. Suryady *et al.* [109] introduced a smart parking system using cloud-based platforms. To achieve a rapid deployment, each gateway, collecting data from parking sensors, is equipped with a cellular upload link in order to store them in the cloud. Then, with RESTful web service and JSON data format, sensed information can be used to reply information requests or be pushed to subscribers through any IoT middleware. Ganchev *et al.* [115] extended their previous work [114] and proposed a number of software solutions, including Kafka/Storm/Hbase clusters, OSGi web applications with distributed NoSQL, a rule engine, and mobile applications, to support a Publish-subscribe service on a cloud-based infrastructure. Kafka, Storm, and Hbase work on distributed message collection and computing. OGSi, a bridge between cloud and user tiers, provides an environment that modularizes web applications by registering or moving in the execution context of the bundle. Pazos *et al.* [111] adopted a central IoT platform Stemys.io to manage all the OSGi-enabled gateways and sensors. In addition, MQTT broker is installed on a central server in order to deal with drivers' parking demands by publishing/subscribing messaging paradigm. ParkITsmart [123] proposed a prototype of parking monitoring and management system, and two apps for end-users and parking providers, respectively. The end-user app is crowdsourced by drivers occupying or releasing parking spaces, the other is updated by parking providers or NFC tags. The authors constructed a stack of the user interface, the web, and platform frameworks by adopting and combining Apache Cordova, jQuery, and jQuery mobile. JSON is used for message formats and JSON-RPC for communications. Two scenarios are simulated to evaluate cruising situations to park in city centers and suburbs. Considering the high popularity (94%) of RFID eTag electronic toll collection (ETC) system in Taiwan, Pham *et al.* [116] proposed a smart parking system based on Arduino with RFID technology. The authors consider each car park as a standalone IoT network. The system contains three parts: a local unit in each car park to collect information, a cloud-based server implemented on Apache Hadoop and Hbase to store the information collected from local units and to allow drivers to find the parking information, and the client application on Android. These local units constitute a geographical parking infrastructure network and allow drivers to access parking information from the cloud via 3G/4G or with local units via wireless networks. Each local unit also maintain a neighborhood table with the latest parking availability information. The authors then proposed an algorithm to describe the system operation to help drivers find the best parking slot according to their cost functions, as well as a function of parking search time and walking distance. Ducreux [125] introduced a resource-based middleware LINC that integrates a rule engine. The goal of LINC is to develop a rapid prototyping platform that can integrate several types of equipment from different vendors and different protocols. A case study of smart parking is taken to present LINC ability and some extra tools that help build a rich user interface and debugging complex systems.

4) User interface: User interface is an important factor to guide drivers to find a parking space by using smart parking system. If the interface is badly designed, drivers might not be aware of the smart parking service or be badly guided by inappropriate information. Souissi *et al.* [107] focused on application layers development, to wit, how to obtain the sensed information from parking sensors and how to present them on a web server. BeeParking [87] adopted a portable identification device, iButton, which is similar to RFID tag. The pre-installed iButton probes, on parking spaces, identify parked vehicles and then show the ambient information on a beehive-like display, which might help drivers to easily understand parking information. Rodier *et al.* [124] described a smart parking educational tool designed by ParkingCarma[13] to facilitate system use. PSOS (parking space optimization service) [119] is an E-parking service including three different parts, that are: a channel manager, an integration manager and an application coordinator, to deal with the interoperability between different devices. Grazioli *et al.* [106] proposed a smart parking online service system, including web and mobile applications for drivers, parking operators, and controllers. Operators can draw parking areas with detailed information. Drivers can be guided to the most suitable parking area by describing their interests. Controllers can monitor all vehicles parked in their own area. Drivers can also share their knowledge about parking occupancy to add crowdsensing to the system. For some countries, such as Singapore, using mobile phones or tablets is strictly prohibited while driving. Niculescu *et al.* [120] proposed an intelligent driver assistant to help drivers find quickly suitable parking in Singapore. The driver assistant uses speech to interact with drivers and becomes an active help during navigation by checking periodically the chosen car park availability.

5) Guidance: Drivers using smart parking services always receive a lot of information. Guidance shall provide a driving path to several potential parking spaces to avoid conflict. Jun [126] presented active and passive parking guidance systems and proposed a system framework for active parking guidance. Since parking guidance is often limited by the dynamically changing availability information and traffic congestion, a negotiation flow is analyzed to reveal some important

[12]www.osgi.org

[13]www.parkingcarma.com

TABLE IV
SMART PARKING CITY PROJECTS

Project	City	#Parking	Cost	App	Launched
Stadtinfo Köln	Cologne	16000	-	-	09/1996
MOBINET	Munich	2750	4M€	-	09/1998
SIMERT	Loja	1974	-	SIMERT Loja Ecuador	05/2002
Area Verda (22@)	Barcelona	50000	-	apparkB	04/2005
Cabspotting(ParkNet)	San Francisco	281364	400$/veh	-	04/2006
PARK Smart	New York City	177	-	Parker	10/2008
SFpark	San Francisco	8200	23M$	SFpark	04/2011
SmartSantander	Santander	400	8.67M€	SmartSantanderRA	06/2011
Parking in Melbourne	Melbourne	7114	537,817$A	Street Parking	07/2011
WSN-DPCM	Madrid	15	3.3M€	-	10/2011
Nice Park	Nice	10000	13-15M€	Nice City Pass	01/2012
Optimod'Lyon	Lyon	30	7M€	Optymod'Lyon	02/2012
Smart Parking Pilot	Beijing	20000	-	-	03/2012
Stockholm Parkering	Stockholm	37000	-	P-Stockholm	05/2012
LA ExpressPark	Los Angeles	6300	18.5M$	Parker,ParkMobile,ParkMe	06/2012
ParkRight	London	3400	889,395£	ParkRight	10/2012
Moscow Fastprk	Moscow	50000	-	Parking Moscow	11/2012
ParkChicago	Chicago	36000	153M$[a]	ParkChicago	04/2014
ParkBoston	Boston	8000	-	ParkBoston	01/2015
Smart Canton	Geneva	16	-	-	01/2015
Berlin Pilot	Berlin	50-70	-	-	09/2015
Citypark Bordeaux	Bordeaux	-	87,000€	Citypark	10/2015

[a]Total project 153M$ for rapid transit bus and parking program

technological problems. SPARK (Srikanth *et al.*) [127] is a smart parking prototype with parking sensors, guiding node, information display, and GSM device. The parking status is sensed by parking sensors and a guiding node can make a reservation via GSM communication. Monitoring, reservation, and guidance modules are implemented to help drivers find parking. Shin *et al.* [128] studied a smart parking guidance algorithm using parking spaces' utility functions. Each parking utility function is calculated from driving duration from current car location to a parking facility, walking distance from a parking facility to a destination, parking cost, traffic congestion caused by parking guidance itself, and the degree of availability.

B. Large-Scale Deployment

Since parking is a city-level problem, large-scale deployments are spreading in different cities. Three main kinds of city-scale deployments are mobile sensing, fixed-site sensing via short-range communication, and fixed-site sensing via long-range communication. The typical example of mobile sensing is ParkNet [58, 59], which takes advantage of the Cabspotting trace [57] in San Francisco to install parking detection sensors on cabs in order to detect the available on-street parking spaces. Since each cab either cruises in the central business district (CBD) to find passengers or drives towards the destination of the current passenger, the CBD has more chance to provide accurate information in ParkNet. With 536 cabs, the successive location information can be updated within 60 seconds apart [58].

Fixed-site sensing requires fixed parking sensors on each parking space. Section III-A introduced many different types of sensors, and we know that most sensors are battery-powered and might sometimes be underground. To maximize sensor devices' lifetime, short-range communication requiring less transmission power is often favorable. To ensure sensors' connectivity, urban infrastructures, such as internet gateways and repeaters, have to be installed within sensors' communication range in order to gather sensed information. The most famous project is SFpark [4], the smart parking municipal service in San Francisco covers 30% of street parking. Sensors and meters can both communicate wirelessly. One repeater at almost each intersection completes wireless mesh networks [4]. 85% of the events can be received in the central server within 60 seconds. The main goal of SFpark is to guarantee a 75% occupancy rate in any parking area by a dynamic pricing policy. Millard-Ball *et al.* [146] took the project and evaluated its impacts of the two first years. The results conclude that the rate changes have helped achieve the city's on-street parking occupancy and reduced cruising by 50%. LA ExpressPark [3] cooperates with Streetline[14] as Park Smart pilot program[15] in New York City. Streetline adopts a time synchronized mesh protocol (TSMP) to allocate bandwidth for each device according to an anticipated frequency-time schedule. The messages can be received by gateway in about 6-7 seconds. LA ExpressPark also applies a dynamic pricing policy to achieve 10-30% of the available parking spaces throughout the day [85].

Nice Park [71] is a smart parking program launched in Nice, France. The wireless parking sensors detecting parking occupancy are provided by Urbiotica[16]. Nice Park installed 68 multi-service kiosks from Finnish Ensto[17] to collect parking information, and provide extra traveling information so that drivers can choose an alternative transport from their parking spaces. Beijing also launched a smart parking pilot program [6] in 2012 and used Timeloit's parking sensors[18] to transmit messages. 35% of on-street parking is covered in Beijing. Real-time parking information is currently used by the government to regulate traffic but it is still not available for the public. Most Asian cities have very few on-street parking, like Beijing (only 5.1%) and Tokyo. Comparatively speaking, Los Angeles and San Francisco respectively have 75.5% and 63% of on-street parking.

WSN-DPCM [66] and SmartSantander [72] are both experimental platforms that deploy, analyze and reproduce different smart city technologies. WSN-DPCM [66] stands for Development, Planning, Commissioning, and Maintenance of WSN in a smart environment. It makes one smart parking demonstrator with 15 parking sensors in Madrid. SmartSantander [72] proposes a unique city-scale experimental research facility for different smart city applications. 400 Libelium[19] parking sensors were deployed to test smart parking service via Digimesh communication. Repeaters and gateways are equipped with Digimesh[20] and 802.15.4 radios in order to communicate with sensors or other 802.15.4 devices. Digimesh is a power-optimized protocol for peer-to-peer WSN and can let all WSN nodes sleep.

SIMERT [131] is an integrated parking system being deployed in Loja, Spain since 2002. 3948 Libelium parking sensors communicate with routers and gateways through Zigbee 900MHz and Digimesh 2.4 GHz. Each parking is equipped

[14]www.streetline.com
[15]www.nyc.gov/html/dot/html/motorist/parksmart.shtml
[16]www.urbiotica.com
[17]www.ensto.com
[18]www.timeloit.com/plus/view.php?aid=99755
[19]www.libelium.com
[20]www.digi.com

with two sensors in order to detect parked vehicles. A parking application is designed to show real-time parking occupancy information to drivers. The authors then introduced a network topology, protocols, and firmware programming for large-scale sensors deployment. Àrea Verda [67] is deployed in Barcelona. Parking sensors update the information to Barcelona Serveis Municipals (B:SM) via parking meters, connected to the existing fiber-optic network. Since 2014, 500 parking sensors equipped with long-range communication technology are being tested as well.

Thanks to Worldsensing[21], SigFox is already commercialized in smart parking markets and used in some cities, e.g., Moscow parking[22] and it is being deployed in Barcelona. SigFox is an ultra narrow band technology to send small-size messages with a very small bandwidth via a cellular link. LoRa has a longer transmission range than cellular networks and provides different energy classes for different applications' needs. Geneva [132] has just launched a pilot project with 16 parking sensors equipped with LoRa in January 2015, in order to evaluate the possibility to deploy LoRa equipped sensors for the Smart Canton initiative. Likewise, thanks to Vodafone M2M[23] and Smart Parking[24], Weightless is now deployed in London (ParkRight [60]) and Melbourne [73]. In addition, Dinh *et al.* [133] analyzed the on-street parking data in Melbourne to find out parking violations, that is, all the parking behaviors that do not comply with the parking rules. The authors also proposed a system architecture to detect those kinds of parking violations.

Table IV gives some information on the budgets while deploying large-scale smart parking systems and services. Thanks to these municipal projects and their corresponding open data, some companies can coordinate parking information and provide drivers a richer platform. Parkopedia[25] also provides some on-street parking information via parking meters and some existing city resident parking maps. ParkWise[26] provides real-time on-street parking information by compiling American city regulations, such as Boston, Chicago, Los Angeles, Cambridge, Somerville, and soon, San Francisco.

C. Parking Vacancy Prediction

Except for reservation, parking prediction is the most common way to forecast the occupancy rate of parking. From predictions, smart parking services can provide the possibility to get a parking space to drivers. That allows drivers to organize their transport before their departures or even during their trips. Many different prediction models can be used to forecast parking demands. Y. Wu [143] introduced five forecasting methods: parking generation rate, vehicle population, land use and traffic impact analysis, a trip attraction based on origin-destination data, and multivariate regression based on historical materials. Considering the lack of parking data and deficient survey precision, the vehicle population model is selected to predict the parking demand of the center area in Changping town, China. The author show a parking demand forecasting from 2011 to 2015 according to car and motorcycle populations. The parking demand is assumed to be directly proportional to vehicle population.

The most popular prediction theory undertakes a Poisson arrival process, and then predicate the system capacity by Markov Chain. Pullola *et al.* [134] modeled the availability of a parking lot by a Poisson process and then proposed an algorithm to give the availability probability for each parking spot when the driver arrives. Klappenecker *et al.* [135] also presumed that the vehicle's arrival follows a Poisson distribution and modeled the parking lot by a continuous-time Markov chain. Then, with the predicted occupancy status, each parking lot can provide cruising vehicles with the availability information via vehicular networks.

Some realistic datasets are collected from large-scale deployments in urban areas. Vlahogianni *et al.* [137, 138] studied on-street parking data from SmartSantander and show that the occupancy and parking periods of four parking areas follow a Weibull distribution. Zheng *et al.* [139] analyzed two parking datasets from San Francisco (SFpark) and Melbourne and predicted the parking occupancy rate by three different methods, namely regression tree, neural network and support vector regression. X. Chen *et al.* [129] also studied SFpark parking data and tried to predict the parking occupancy status in order to provide a better service. Richter *et al.* [136] compared several different spatiotemporal clustering strategies by studying the parking availability data from SFpark project. Even spatial and temporal clusterings cannot provide a more accurate fit than the 7-day model (from Monday to Sunday), they can reduce the required storage size. Demisch [144] also analyzed the parking data collected by smart parking meters. Since parking sensors lifetime is short, providing parking information on smart parking meters is essential, especially for the dynamic demand-responsive pricing. That is to say, the city uses historical data to develop an estimation model to predict parking occupation and adjust parking rate based on a sensor independent rate adjustment model. Rajabioun *et al.* [15, 141] used real-time parking data from San Francisco and Los Angeles and then proposed a multivariate autoregressive model to predict temporal and spatial correlations of parking availability. Prediction errors are used to recommend the parking location with the highest probability of having at least one parking spot available at the estimated arrival time. Ji *et al.* [142] collected parking availability data in several off-street parking garages in Newcastle to investigate the changing characteristics of short-term available parking spaces. This forecasting model is based on the wavelet neural network method and compared with the largest Lyapunov exponents method in the aspects of accuracy, efficiency, and robustness.

If you ever benefited from Citymapper, you will not feel unfamiliar with Optimod'Lyon. Optimod'Lyon [130] is a project to optimize urban mobility when citizens are using public transport, sharing bikes, carpooling or driving their private cars. Smart parking is also one part of this project to provide real-time parking information and navigation. Opti-

[21] www.worldsensing.com
[22] parking.mos.ru/en/
[23] m2m.vodafone.com
[24] www.smartparking.com
[25] en.parkopedia.com
[26] parkwise.us

mod'Lyon's principal partner, Parkeon[27], benefiting from their ubiquitous parking meters, exploits a Big Data architecture to unveil the mask of on-street parking. Parkeon adopted Dataiku's Data Science Studio[28], a machine learning method, to analyze historical data and build a predictive model to find parking in cities. Besides, Optimod'Lyon also installed 30 parking sensors in Lyon city center, a MicroRadar from Sensys Networks[29], that has a 3 meters detection range and better distinguishes the differences between vehicles, partial vehicles, and bicycles than the common magnetometer.

Qucit, a French start-up, made the first appearance with a public bike prediction app, "Bike Predict". This app provides possible available bike storage or parking on each bike sharing station from now to 45 minutes later in more than 30 French cities. The predicted information is expressed by probability. This algorithm does not only analyze when bike stations are filled or emptied, but also consider the weather effect, which usually changes the mood of citizens to circulate by bike. Citypark [145] is the second app from Qucit and it began in Bordeaux. Citypark inherited the idea of Bike Predict and it is proved that the flow of filled or emptied public bikes stations is highly related to traffic flow. By integrating public bikes information with the existing connected parking meters, traffic monitoring cameras, weather, special events and crowdsensed data, Citypark estimates the time required to find on-street parking near your destination.

Besides, drivers' decisions can also be influenced by prediction. E. Wu *et al.* [140] proposed a cost model to influence users' parking choice. The cost model is based on a probability of parking successfully, within a certain distance from the current location. Since the successful parking probability varies with time, a probability estimation method is proposed by using remaining available space count. Koster *et al.* [80] used smartphones as parking detection sensors and then studied the traffic of NYC department in order to estimate parking lots occupancy status. Then, to calculate the availability probability of each parking space, the estimator considered all the properties of parking spaces (shade, sun, garage and cloudy) to know if the space had a higher chance to be taken. The smart parking system can then use the information to recommend drivers the most favorable parking space. David *et al.* [76] designed an event-oriented forecasting model as part of MOBINET project[30]. The forecasting model considers the detected information (mainly for off-street parking) and estimated information from the online traffic data (mainly for on-street parking).

V. PARKING SERVICE DISSEMINATION

Once parking information is detected by sensors and stored in order to be accessible to the public, drivers access the same information and cruise in the same area where they often chase the same parking space. Thus, how to broadcast information and guide drivers to corresponding parking spaces fairly becomes an important issue. In this section, we will introduce how to disseminate parking information and how drivers react according to the information they receive. We divide service dissemination into three parts as well: information dissemination, parking competition, and drivers' behaviors, which are dedicated in Table V. Information dissemination involves the diverse technique choices. We have seen the centralized solutions in the previous literature. In this part, we will introduce distributed or opportunistic solutions inspired by vehicular networks. Parking competition presents the provoked decision making when drivers are connected to the parking availability information from the system's viewpoint. Parking behavior inspects driver's decision from the driver's viewpoint. All the different individual behaviors can help model global parking competition and choose a better technique to display parking information.

A. Information Dissemination

In Section IV-B, all the existing large-scale deployments adopt a centralized method to provide parking information via cellular link or WiFi. Fig. 4 classifies different parking information dissemination techniques. We categorize them into two macro groups: centralized and distributed. In Section IV-B, we notice that centralized information transmitted through BTS of 3/4G or WiFi AP is the most intuitive choice of municipalities. We also define all the roadside infrastructures connected directly to centralized servers that are running a centralized technique. Then, vehicles executing a vehicle-to-infrastructure communication are also connected to the centralized server via one-hop. Next, the distributed techniques are more varied. The first sub-group is determined by a roadside infrastructure. We define that VMS is distributed to one-hop roadside infrastructures since they only provide local information and there is no communication between drivers. If vehicles can exchange messages, parking information, traveling from infrastructures to drivers, will be able to be retransmitted to other drivers in a multi-hop network. If there is no roadside infrastructure, we suppose that sensors and vehicles are able to communicate. It means that either fixed sensors can execute a sensor-to-vehicle communication with passing cars, or cars equipped with sensors can exchange their detected information with other cars in a vehicle(sensor)-to-vehicle network. The latter usually can retransmit receipt messages in a multi-hop manner.

Except for the existing cellular networks and for WiFi, a centralized information flow supported by roadside infrastructure and vehicular networks is also very common. CBPRS [168], namely city-based parking routing system, proposed a centralized parking system that links intelligent lampposts and parking sensors by power-line communication. The central parking service runs an ant colony optimization (ACO) to guide drivers from their current location to parking spaces. The results show that ACO outperforms the Dijkstra's algorithm in reducing traffic congestion and increasing city flow. Piorkowski *et al.* [147] used TinyNodes[31] as parking sensors. Sensors periodically send available parking information to vehicles so that vehicles can find parking spaces

[27]www.parkeon.com
[28]www.dataiku.com
[29]www.sensysnetworks.com
[30]www.mobinet.de
[31]www.tinynode.com

TABLE V
SMART PARKING SOLUTION FOR SERVICE DISSEMINATION

	Reference	Info source		Deployment		Storage			Service				Parking game			Network	
		Type	S/P	NetS	NetU	C	D:s/v	D:I	AU	BC	EP	Rsv	UB	SG	PD	NP	OT
Information dissemination	Piorkowski [147]	3	25/25	XE1205		-	S	-	2	VNT	√	-	-	-	-	-	-
	Lochert [148]	3	*/real map	802.11		-	S	-	10K	VNT	-	-	-	-	-	-	AG
	SPARK (Lu) [149]	12	*/1000	802.11		-	V	3	Pois(6)	VNT	√	√	√	-	-	-	SC
	Alhammad [150]	12	-	802.11		√	-	√	-	-	√	√	-	-	-	-	-
	Bessghaier [151]	12	-	802.11		-	V	-	≤300	VNT	-	-	-	MAS	-	-	-
	edPAS [152]	mob	*/50000	802.11		√	-	1000	100K	-	√	-	-	SH	-	-	-
	Panayappan [153]	mob	-	802.11		-	-	√	-	-	√	-	-	-	-	-	SC
	iPark (Zhao) [154]	mob	*/2000	802.11		-	V	-	≤2K	VNT	√	-	√	-	-	-	-
	Delot [12, 155–158]	14	*/60	802.11		-	V	-	60-240	VNT	-	√	-	-	-	√	-
	Kokolaki [83, 159]	fixed	*/25	802.11		√	S	-	5-70	VNT	-	-	√	-	-	-	-
	Tasseron [160]	3,14	*/96	S2V,V2V		-	S,V	-	≤96	VNT		-	√	-	-	-	-
	Caliskan [161, 162]	fixed	*/∼129·70	-	802.11	-	V	129	10K	VNT	√	-	-	MC	√	√	AG
	Horng [163, 164]	-	*/200-1200	-	802.11	√	-	100	300-1.8K	VNT	√	-	-	CA	-	-	-
	PMNET [62]	1[a]	-	-	802.11	-	-	√	-	VNT	-	√	-	-	-	-	-
	Vaghela [165]	-	-	-	802.11	-	-	100	100	-	√	-	-	AD	-	-	-
	Kim [166]	-	-	-	VLC	-	-	-	-	VNT	-	-	-	-	-	-	LQ
	PhonePark [81, 167]	14	*/16	BT	802.11	-	V	-	-	VNT	√	-	-	-	√	-	-
	Wang [65]	2,7	*/real map	802.15.4	Wifi,CN,BT	√	S	-	Real trace	VNT	√	√	-	-	√	-	-
	CBPRS [168]	fixed	-	WSN	802.11,PLC	√	-	√	7.5K-10K	VNT	√	√	-	ACO	-	-	-
	Geng [169]	3,5	*/2611	WSN	802.11,CN	√	-	-	Pois(0.4)	VMS	√	√	√	-	-	-	-
	Draskovic [170]	3,4	-	WSN	BT	√	-	-	-	-	√	-	-	ES	-	-	-
Competition	Zoeter [85]	3	*/6300	WSN	Wifi,CN	√	-	-	-	-	√	-	-	MC,DP	-	-	-
	Millard-Ball [146]	3	11900/8200	WSN	Wifi,CN	√	-	-	-	-	√	-	-	DP	√	-	-
	Song [171]	-	-	-	-	-	-	-	-	-	-	-	-	GT	-	-	-
	Verroios [64]	12	-	802.11		-	V	-	20 veh/km	-	√	-	√	CT,TSP	-	-	-
	Ayala [172–174]	12	*/20-80	802.11,CN		√	V	-	40-80	-	√	-	-	GT,SM,GPA	-	-	-
	iParker [175]	-	-	-	-	√	-	-	Pois(λ)	-	-	√	-	DP	-	-	-
	Chou [176]	-	-	-	802.11,CN	√	-	√	-	-	√	√	√	MAS	-	-	-
	Dell'Orco [177]	-	-	-	-	-	-	-	-	-	-	-	√	MAS,FZ,DP	-	-	-
	Karaliopoulos [178, 179]	-	-	-	Wifi,CN	√	-	-	-	-	√	-	√	GT	-	-	-
	Di Napoli [180]	10	-	-	Wifi,CN	√	-	-	-	-	√	√	-	MAS	-	-	-
	Schlote [181]	-	*/100-160	-	Wifi,CN	-	-	√	Pois(6)	VNT	-	-	-	SH	√	-	-
	Jin [182]	-	-	-	-	√	-	-	1500	-	√	√	-	SH	-	-	-
	PFLBS [183]	-	*/73+32	-	-	√	-	-	-	-	√	-	-	FZ	√	-	-
	Teodorović [184]	-	*/100-350	-	-	-	-	-	-	-	-	√	-	FZ,DP	-	-	-
	Sarasua [185]	-	*/5567	-	-	√	-	-	5567	-	√	√	-	HTA	-	-	-
	CGPS [186]	mob	*/20-80	802.11		-	V	-	25-85	-	√	-	√	GT	-	-	-
	Doulaims [187]	mob	-	802.11		√	-	√	-	-	-	√	-	MIS,DP	-	-	-
Behavior	Mei [188]	fixed	-	-	-	-	-	-	-	VMS	-	-	√	GA	-	-	-
	Caicedo [189, 190]	3	*/∼600	-	-	-	-	-	Pois(38-98)	-	-	-	√	-	√	-	-
	PARKAGENT [191]	-	*/10340	-	-	-	-	-	11.6K	-	-	-	√	MAS	-	-	-
	Jossé [192]	-	*/5-20	-	-	-	-	-	100	-	-	-	√	-	-	-	SA
	H. Guo [193]	-	*/800	-	-	-	-	-	≤2K	-	-	-	√	CA	-	-	-
	L. Guo [194]	-	*/113+526	-	-	-	-	-	≤800	-	-	-	√	-	-	-	-
	Ma [195]	-	*/604	-	-	-	-	-	-	-	-	-	√	-	-	-	-
	M. Chen [196]	-	*/188	-	-	-	-	-	-	-	-	-	√	-	-	-	-
	Nurul Habib [197]	-	-	-	-	-	-	-	46K	-	-	-	√	-	-	-	-
	Glasnapp [198]	3	*/6300	WSN	Wifi,CN	√	-	-	-	-	√	-	√	DP	√	-	-
	Chaniotakis [199]	-	-	-	-	-	-	-	397	-	-	-	√	-	-	-	-
	Shaaban [200]	-	*/4100+	-	-	-	-	-	816	-	-	-	√	-	-	-	-
	Yu [201]	-	-	-	-	-	-	-	-	-	-	-	√	-	-	-	-

†In the Type column: the type id is referred to Table II.
†In the Info source columns: S/P is the ratio of sensors to parking places.
†In the Deployment columns: NetS is the network of sensors. NetU is network of users (CN: cellular network; CB: cable; BT: bluetooth; PLC: power-line communication; VLC: visible light communication)
†In the Storage columns: C is centralized. D is distributed (S/V/I: sensor/vehicle/infrastructure).
†In the Service columns: AU is amount of service users (Pois: poisson - unit: vehicles/minute), BC is broadcast (VMS: variable message sign, VNT: vehicular network), EP is E-Parking (namely drivers can find parking through telephone or the Internet). RSV: reservation.
†In the Parking game columns: UB is user behavior, SG is strategy (ACO: ant colony optimization; AD: agent discovery; CA: cellular automata; CT: clustering algorithm; DP: dynamic pricing; ES: Expert System; FZ: fuzzy logic; GA: genetic algorithm; GPA: gravity-based parking algorithm; GT: game theory; HTA: Hitchcock transportation algorithm; MAS: multi-agent system; MC: Markov chain; MIS: maxima interval scheduling; SH: scheduling algorithm; SM: stable marriage; TSP: travelling salesman problem). PD is prediction.
†In the Network columns: NP is network protocol, OT is others (LT: lifetime; SC: security; AG: aggregation; LQ: link quality; FW: framework; SA: search algorithm)

from nearby ones. Alhammad *et al.* [150] also proposed a smart parking based on sensing vehicles. The difference is that plenty of infostations are installed for each parking area in order to gather/provide information from/to vehicles. Horng *et al.* [163, 164] proposed a V2I communication model between roadside infrastructure and vehicles to deal with parking demands. A cellular automata mechanism is used to describe the car society under a smart parking environment to allocate parking spaces more efficiently. Wang *et al.* [65] proposed a smart parking reservation system in a half distributed manner. Drivers get parking information from a central server but reserve their parking spaces directly with the nearby parking spaces. To test this system, the authors used a real-world traffic trace to generate parking demands. The authors took a general assumption that real total traffic for parking is proportional to highway traffic and then classified the total highway traffic

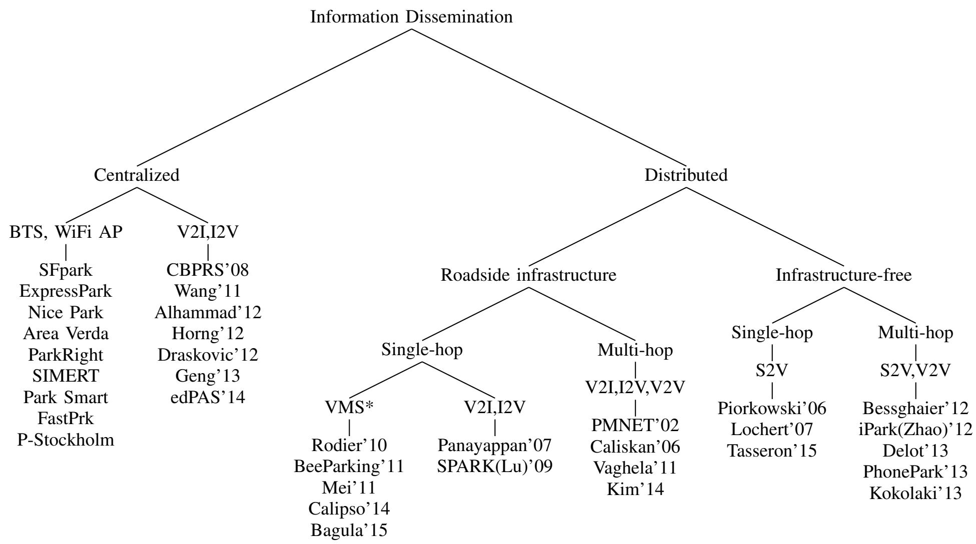

Fig. 4. The diagram of parking information dissemination classification. BTS: base transceiver station; AP: access point; V2I: vehicle-to-infrastructure; I2V: infrastructure-to-vehicle; V2V: vehicle-to-vehicle; S2V: sensor-to-vehicle; V2S: vehicle-to-sensor; VMS: variable message sign.

into incoming traffic and outgoing traffic, which represents the traffic approaching the target area and leaving it. The incoming traffic serves as reference of parking demands. After that, a real-world map in Los Angeles Downtown is imported into the simulator to calculate distance and path. Geng *et al.* [169] formulated a mixed-integer linear programming problem for smart parking demands and solved it with an optimal parking allocation method. Draskovic *et al.* [170] introduced a smart parking system using a search algorithm to find the most suitable parking spaces as soon as possible.

Since the information delay caused by network retransmission is somehow long, the distributed information system is considered an appropriate solution to reduce network distance and network traffic. VMS is an instinctive way to indicate the adjacent available parking information to drivers. Here, we classified VMS as distributed manner because VMS only shows the information in a certain nearby area. Alternatively, drivers can also receive information from roadside infrastructure in one-hop. Panayappan *et al.* [153] proposed a VANET-based infrastructure to provide available parking information, thus roadside units deployment is very important in order to cover each public or private parking area. Each vehicle can detect the occupancy status and send it to roadside units. Each vehicle can also get the update occupancy from roadside units. Data storage is distributed among different roadside units, which can be better protected to avoid some security problems.

To extend the information popularity (more accessible), messages can travel for more than one-hop from infrastructure in order to reach some vehicles which are not in the city infrastructure transmission range. We have seen parking meters' importance for industrial cycles in Section III-C. Most vehicle-to-vehicle communications can benefit from these existing roadside parking meters to increase their packet transmission rates. Caliskan *et al.* [161, 162] presented a decentralized parking discovery method supported by automats, namely roadside parking payment terminals. Since automats deal with payments, they also have current occupancy information and can periodically broadcast available parking information to vehicles. Each vehicle aggregates received information before it distributes it to other vehicles. Vaghela *et al.* [165] also used parking meters (automats) to distribute parking information for passing vehicles. PMNET [62] means parking meter network. Infra-red sensors are installed on parking meters to detect the occupancy status, and then parking meters can announce the available parking information via direct communication with vehicles. Vehicles can also forward this information to further vehicles to increase parking usage rates. Another new highly anticipated technology is visual light communication (VLC), which exchanges messages through light. The VLC module includes a LED as a light transmitter and a photodetector as a light receiver. Since light travels in straight lines, VLC modules can communicate in the light-of-sight. Kim *et al.* [166] proposed a smart parking information system supported by VLC. The authors installed these VLC modules on vehicles and in parking lots entrances, and then drivers could obtain parking information while passing the entrance. The packet reception rate is about 80% and the transmission range is limited to 1.7 meters.

However, urban infrastructure installation is costly, so vehicles can also choose to communicate directly with sensors themselves. Lochert *et al.* [148] implemented an aggregation mechanism for data dissemination in vehicular networks. A real map is taken and TinyNodes parking sensors are supposed to be deployed on it. Similarly to [147], parking availability information is periodically broadcasted. SPARK (Lu *et al.*) [149] suggested that sensor-mounted vehicles could sense the parking status and disseminate it by their own. Tasseron *et al.* [160] compared two kinds of sensing methods in vehicular networks: sensor-to-vehicle (S2V) and vehicle-to-vehicle (V2V). In the S2V scenario, sensors are installed on parking spaces and transmit the occupancy status to nearby vehicles. In the V2V scenario, vehicles can detect their own status (parking or unparking) and send the information of an available parking space while unparking. The results show that

S2V can improve parking search efficiency under almost all conditions. V2V can only outperform S2V in situations with almost full on-street occupancy levels.

As previously mentioned, multi-hop can increase information popularity. Bessghaier *et al.* [151] studied a full distributed inter-vehicular network to see if parking search time decreases, compared to current blind search. edPAS [152] stands for event-driven parking allocation system. Drivers can subscribe to an event place and then get the update from communicators if there is any change in the information they asked for. The authors compared two different parking demand allocations: first come first serve (FCFS) and priority (PR). The results show that PR outperforms FCFS. iPark (Zhao *et al.*) [154] worked on parked vehicles that had searched available parking spaces while other vehicles could inherit the information in order to reduce parking time. Delot *et al.* [12, 155–158] proposed a reservation protocol to allocate parking spaces in a fully distributed environment. Each vehicle can release an available parking message to the network and look for a potential parker. If a vehicle gets a response, the parking space is then reserved. Otherwise, a new coordinator shall be chosen in order to look for a potential parker in a further area. PhonePark [81, 167] used sensors on drivers' smartphones to detect their activities, e.g., accelerometer, Bluetooth, and GPS. Both accelerometers, which can sense drivers' movements, and Bluetooth, pairing between vehicular onboard units and smartphones, can indicate if a driver is in the car or not. GPS can provide a driver's spatial and temporal information in order to charge parking fees. When a driver enters his/her car and is ready to leave, the parking space will be available for someone else. Thus, the car will advertise this information to other vehicles and a vehicular network is then formed to share parking information according to the detected drivers' behaviors. Kokolaki *et al.* [159] proposed an opportunistically assisted parking search (OAPS) in S2V and V2V communications. Some results are shown by comparing blind and central assisted search. The central parking search can help drivers find parking faster but OAPS can help drivers find a closer parking space. Since information dissemination is supported by drivers themselves, it is considered a crowdsourcing dissemination network. Drivers can decide to distribute the information they received (forwarder), to falsify the information and distribute it (selfish liar), or do nothing (freerider) [83].

B. Parking Competition

Dynamic pricing is currently the most efficient way to regulate parking occupancy status and traffic congestion. Unlike the dynamic pricing policy of SFpark, which changes the parking price on the average occupancy in a review period, Zoeter *et al.* [85] took LA ExpressPark deployment and proposed a dynamic pricing policy with a Markov Chain model. The model can then predict a number of parking demands and adjust the price before the car park is congested (occupancy rate $> 90\%$) or underused (occupancy rate $< 70\%$). Doulaims *et al.* [187] improved smart parking reservation policies by using maximal interval scheduling and dynamic pricing. iParker [175] proposed a mathematical optimization model while using dynamic pricing for smart parking. The objective of this model is to minimize drivers' total monetary cost while maximizing parking resources use. Chou *et al.* [176] modeled the parking price negotiation in a multi-agent system. Each parking manager announces the parking spaces and waits for the bids from potential parkers. Thus, the parking price will dynamically change according to the intensity of competition. Dell'Orco *et al.* [177] also proposed to match parking demands and supplies under dynamic parking pricing by using a multi-agent system. The drivers' perceived parking cost is described by a fuzzy set in order to present their imperfect knowledge on both parking and system status. Di Napoli *et al.* [180] adopted a software agent negotiation mechanism, which establishes an agreement between drivers and parking manager considering drivers' preferences, e.g., location and cost.

Fuzzy logic system can be used to describe drivers' decisions. PFLBS [183], namely parking finding location-based service, is developed based on a case study of the Oats Street and Carlisle PnR facilities in Perth, Western Australia. Fuzzy logic forecast models were used to estimate the uncertainty of parking availability during the peak parking demand period. Teodorović *et al.* [184] referred to the municipal parking projects, such as in San Francisco, Chicago, Seattle, and proposed a fuzzy logic system in order to know when to accept or reject a new parking request according to the pricing policy.

Drivers might get a list of potential parking spaces and visit them one by one until they get one. Thus, the path between different parking spaces is quite important according to their locations and availability probability. Verroios *et al.* [64] targeted the traveling path planning while driving to parking spaces. When drivers send their parking requests to the roadside infrastructure, they get a list of available parking spaces with a probability of still-free. Each vehicle uses a clustering algorithm to classify parking spaces and then plan the trip as a time-varying traveling salesman problem.

However, parking competition is interactive. If we try to look at the entire system from a bird's eye view, each driver is involved in a parking game and each decision might have a butterfly effect. Song *et al.* [171] modeled parking search as a game and then analyzed if the municipal parking policy is suitable. Ayala *et al.* [172–174] focused on the parking competition. Drivers shall be assigned a parking space they prefer, otherwise, the parking assignment will not be stable, namely the marriage problem. The authors modeled the parking decision by a gravity-based parking algorithm and a game theory model. That is to say, drivers will calculate the gravity value of each parking space with respect to themselves and their neighbors and take the parking space with a relative higher gravity value. Karaliopoulos *et al.* [178, 179] analyzed on-street parking and car park parking choice. By assuming that each driver can know how many competitors he/she has for on-street parking, drivers might change their mind and provoke a chain reaction. A game-theoretical model is formulated for drivers' decisions. The authors show parking search efficiency between optimum, priority heuristic and Nash equilibrium. CGPS [186] stands for a collaborative game in parking lot search. The authors evaluated CGPS based on game theory in a

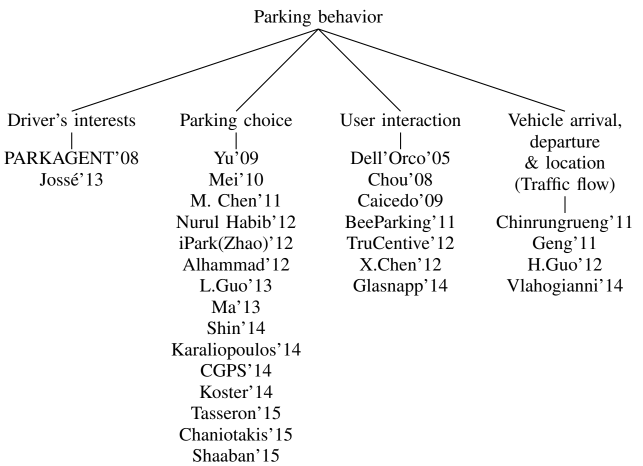

Fig. 5. The diagram of parking behavior classification according to different focuses of drivers' behaviors.

distributed vehicular networks. To collaborate, not only did all vehicles receive their own cost but also opponents' extra cost. Based on this, Nash equilibrium is generated by parking search efficiency increase. Sarasua *et al.* [185] presented a parking distribution way using the Hitchcock transportation algorithm. Since it considers network costs, very realistic solutions were given and the system equilibrium could be achieved through optimal parking assignment combined with pre- and post-game traffic control strategies. Jin *et al.* [182] considered parking space assignment fairness. Since most drivers cannot arrive the assigned but too far parking spaces on time, the assignment scheme is not fair and shall take real-time traffic information into account. The traditional First-Come-First-Served manner is not suitable to cope with parking competition in rush hours. The authors proposed an algorithm considering walking distance, driving direction and a time limit of arrival. Schlote [181] proposed a parking space assignment based on RED[32]-like scheduling algorithm. The authors assumed that vehicles only listen to broadcast information from car parks and then estimate the availability of a parking space. The authors extended the estimation model from a single car park to several distributed car parks considering feedback efforts to choose a car park.

C. Driver's Parking Behavior

Fig. 5 shows different classifications while considering parking behaviors. Four categories are made according to the criteria used to analyze drivers' behaviors. Traffic flow is often used in a mobility analysis because it is strongly related to urban layout. User interaction includes the literature previously mentioned on user interface design and the impact of different parking policies on drivers, e.g., dynamic pricing. Driver's interests are usually used to build simulation platform, such as an agent-based system for publish-subscribe service. Parking choice is the most common method that investigates existing studies to induce all the limited possibilities. H. Guo *et al.* [193] formulated the numerical models for through traffic or parking and unparking vehicles and executed them in Monte-Carlo simulation. By changing the probabilities of (un)parking and vehicle arrival rates, traffic and system capacity are also affected.

Considering the parking game, all drivers have their preferences. PARKAGENT [191] is an agent-based, spatially explicit model for city parking. It simulates drivers' behaviors to generate distributions of key values, e.g., search time, walking distance, and parking costs over different driver groups. It also shows that additional parking supply linearly affects extreme values occurrences, but has only a weak impact on the average search time for a parking space or the average walking distance between the parking space and the destination. Jossé *et al.* [192] worked on a search algorithm while coping with parking queries. The authors generated 100 test cases on real world street map data in Munich containing 40186 nodes and 96047 links. They compared greedy and brute-force search algorithms. Greedy search algorithm outperforms on runtime under all conditions and on accumulated vacancy probability when there are more than 20 parking spots. Glasnapp *et al.* [198] defines intercept and online surveys in the context of LA Express Park. The results determine, in an ethnographic point of view, if drivers are aware of the dynamic pricing policy.

Depending on drivers' preferences, they might repeat parking search until they get one or they give it up. M. Chen *et al.* [196] firstly introduced influencing parking space choice key factors and evaluated drivers' micro-behaviors in parking lots. Then, the authors modeled an optimal parking space choices according to fuzzy multiple attribute decision making. Mei *et al.* [188] described a parking choice behavioral model incorporating drivers' perceptions of waiting times at car parks based on VMS near Shanghai. Then, the arrival rates were estimated based on driver characteristics, car park attributes and availability information. By using a genetic algorithm, queue length and total travel time are reduced. Caicedo *et al.* [189] introduced a PARK (parking access and revenue control) system and tried to change the information for drivers in VMS, to see how drivers change their decisions and if parking search time is reduced. The authors also proposed a methodology to predict real-time parking space availability [190]. L. Guo *et al.* [194] proposed two kinds of parking choice models: a static game-theoretic model and a dynamic neo-additive capacity model in order to capture the competition between drivers for limited parking spaces. The static game assumes that drivers make decisions simultaneously with perfect knowledge of the parking system characteristics. The dynamic model considers individual drivers' psychological characteristics under uncertainty, i.e., optimistic and pessimistic attitudes, and captures the impacts of the irrational side of parking behavior as well as the rational aspect. The results show that the dynamic neo-additive capacity model has a higher predictive accuracy than the parking system. Ma *et al.* [195] used six parking facilities in Beijing Lama Temple to investigate drivers' parking behaviors around the tourist site. The authors developed a multinomial logistic regression model that reveals the relationship between parking decision

[32]RED: random early detection, a scheduling algorithm, which accepts all the requests when the buffer is almost empty. But if the buffer grows, the probability of dropping an incoming packet increases as well.

and influential factors. Nurul Habib *et al.* [197] used a sample data set collected in Montreal, Canada. Since travel demand modeling has been undergoing a paradigm shift from the traditional trip-based approach to an activity-based approach, the authors gave strong evidence that the parking type choice influences the activity scheduling process. Yu *et al.* [201] focused on drivers' parking choice behaviors while choosing an on-street or off-street parking space. The authors studied two groups. The first group was collected from drivers with complete parking information, and the second from drivers with incomplete parking information. The results showed that compared with completely-informed drivers , incompletely-informed drivers prefer to pay less attention on walking time and safety but more on parking fee and some other factors. Chaniotakis *et al.* [199] made a survey to see how drivers choose their parking spaces according to the probability of having it. A higher availability of parking after 8 minutes of search time is more important than a lower parking availability upon arrival. Four essential factors in determining parking space decisions are, in order of importance, parking costs, uncertain parking availabilities (availability after 8 minutes), walking distance to destination, and parking availability upon arrival. Shaaban *et al.* [200] studied the survey data to understand drivers' parking choices in commercial centers of Doha, Qatar. The authors chose four different parking lots around the city center mall and tried to understand the parking choices according to drivers' gender, nationality, age, income, visit frequency and stay time. Since drivers have to walk under the sun at $50°C$ in summer, the walking distance from parking lot to destination is a very important factor. The authors adopted binary classification tree models and figured out the factors associated with different parking choices. The results show that smart parking affects drivers' decisions significantly more than amenities themselves.

VI. CHALLENGES AND OPEN ISSUES

Unquestionably, parking is really a pain for all drivers in the world. With the parking information, collected either from cities' parking sensors or from crowdsensing apps, smart parking services can provide platforms with real-time parking status for drivers. Thanks to them, drivers can shorten their traveling time and cities can increase their revenues from parking fees and tickets. Most smart parking implementations focus on the sensing technology and mobile apps development. For this reason, cities' deployments build a bridge between them. A Large-scale deployment is a good opportunity to test the sensing accuracy and sensors' connectivity [4, 72]. Sensed information can be stored in servers and provided to the current apps. In this paper, we proposed a comprehensive classification of smart parking solutions. All works are visualized in detailed tables to show the different research focuses. The results presented in the earlier sections are numerous and diversified, covering different disciplines and topics. We understand how important it is to work on smart parking solutions and it induces many open questions. Our comprehensive survey puts us in a particular place to synthetize and analyze the existing works and to bring into some open questions. In this section, we give a summary and discussion along the line of our classification.

Sensing: We have introduced diverse parking detection sensors and their sensing techniques in Section III-A. Since cities intend to monitor and manage their own resources anywhere and anytime, fixed sensors are usually preferable. Most municipal deployment projects embedded plenty of magnetometers on on-street parking spaces, and then gather parking availability information via wireless sensor networks or cellular links (Table III). But magnetometers are difficult to be adopted in un-demarcated spaces and the installation and maintenance cost is significant. Some new fixed sensors are proposed and tested, such as mini radar or multi-sensor devices. Smartphones are alternative multi-sensor devices to detect empty on-street parking spaces from the user end, and they are often proposed by companies. But their wide range use is controversial because it involves personal privacy and information security, and requires popularity and incentive participation.

Sensor connectivity: Sensors deployed in cities have to be managed through wireless networks. Short and long-range communication techniques are both used in municipal deployments in Section IV-B. Both of them are dedicated to sensors' lifetime and autonomy, and information delay. Long-range communication can benefit from the existing radio access network and gives a prompt connection when needed. But to be energy-efficient, the amount and the size of data transmission are very restricted. The future extension requires the mature technology of the future generation of mobile network (5G), and packets often travel farther among many central units and are billed. Short-range communication allows some small-size deployment for local service. Data transmission is often unlimited and compatible with present wireless networks. Moreover, it gives interesting features to maintain local information and can be the preliminary framework of smart cities. Although there are many types of research on short-range communication, very few of them aim at deploying parking spaces on a large-scale. On the contrary, long-range communication proposes a better business model and a simpler and prompt deployment to noticeably enter the market.

Centralized or distributed: Fig. 4 shows different possibilities to store and disseminate parking information. Is the infrastructure necessary for urban services? An infrastructure-based system usually relies on roadside infrastructure (usually distributed) or cellular base station (centralized) to provide information from parking detection sensors. Otherwise, sensors need to be able to communicate directly with drivers to tell their own status with more anticipated battery capacity in an infrastructure-free mode. Since cities always like to monopolize urban data, centralized storage is normally favorable. Also, thanks to smartphones popularity and ubiquitous data network provided by mobile operators, drivers are able to benefit from urban information simply via apps in a centralized manner. However, real-time parking availability data is useful only when drivers are very close to the parking location. The distributed storage and dissemination can keep local parking information, without traveling far, and can generate useless transmission. Moreover, omnipresent roadside parking meters owning real-time parking data are equipped with more interfaces and more computing power such as to communicate with parking sensors, passing vehicles and some WiFi APs intelligently. With the emerging concepts of ETSI LDM[33] and Cisco Fog computing, it will be interesting and possible to use them for new geolocalized urban services.

Future data network: Today's Internet is in a very different place, having turned into a constellation of massive data, cloud software, smartphone apps, e-commerce transactions, and social media. Concerning smart parking, networks are full of data, interests, and e-parkings. Data packets describe both parking and interests information one specifies in a parking request. Smart parking system is an essential part to deal with all the parking resources and requests in order to achieve e-parking services. Some frameworks or architectures for the integration of different technologies and software packages are presented in Section IV-A. Most of them are cloudifying the system for the future Internet of everything. Such kind of network shall be capable of matching different interests to the most appropriate data, that is, the future data network[34]. A simple data-interest matching has been implemented in several well-known apps, like Airbnb and Uber, which guide users to find the particular information they need. Smart parking requires more intelligent data matching and interest adaptation since users have to drive their cars and use this app simultaneously, e.g., OMG's Data distribution service (DDS) within ETSI LDM for vehicular communications.

Data analysis: Since cities own parking spaces' spatiotemporal information, studying data characteristics is essential to improve system efficiency and parking policy. The first purpose is often to propose a vacancy prediction model from collected data so as to show drivers simplified and understandable information. Besides, the information can also be applied in service dissemination while drivers are completing limited parking spaces. Parking is a problem related to land use, vehicular traffic, cities revenues and human flow. The statistics on parking data will be able to indicate key factors for urban development from technical, economical and environmental perspectives. The emerging Big Data gives a hotbed for parking meter suppliers and data scientists to predict parking availability without installing physical sensors. Some machine learning algorithms have aimed at improving matching time and accuracy, e.g., deep learning for information retrieval and multimodal interaction, and Dataiku for parking prediction. However, we do not have an idea yet which algorithm is the best for geolocalized data and service.

Connected vehicles: As the opportunity for the connected car market is huge and its compatibility with existing wireless network is promising, car manufacturers are now adapting their cars into CALM architecture[35]. Current smartphone apps used by drivers cruising on the street are not proactive. A content-based and context-aware parking service facility will be needed, allowing to match drivers' interests and display parking information in advanced drive assistance systems (ADAS) through the DDS messaging protocol. Also, vehicular networks are more sensitive to urban environment, especially on urban propagation, mobility, and drivers' behaviors. The microscopic traffic simulation seems a key point while proposing new inter-vehicular services. A more realistic dataset describing vehicular activities shall be collected and modeled to evaluate and improve smart parking systems from the user end.

Parking competition: Large-scale deployment gives some real-world examples while integrating parking sensors with the software system. However, most drivers still have problems on finding parking because all drivers having the same information always chase the same parking space. Also, drivers often do not get the proper information, e.g., parking spaces that are not on their ways. Thus, the information dissemination shall reduce the traffic flow instead of making drivers cruise more for parking. Parking competition is then focused to understand how drivers' decisions can affect the parking system performance. Most systems suggested drivers to make a reservation to avoid conflicts. Besides, dynamic pricing and game theory are currently the two most instinctive methods. To define the parking game, each driver's individual behavior is significant, e.g., a vehicle's arrival and departure, a user interaction with the parking system through smartphone or VMS, the parking choice, and the driver's interests. Vehicles' arrivals and departures are often characterized by Markov Chain and combined with historical data for parking prediction.

Municipal or individual: Although there are some non-governmental smartphone apps to gather parking information from everywhere in the world, such as Parkopedia, or crowdsourcing apps (e.g., Apila), their popularity and convenience are still very limited. With the influence of Uberisation, cities are not the only urban service providers anymore. Gaparking rose up to offer idle private parking spaces for more than one user. Except on-street parking and car parks, drivers have one more choice to get a (usually indoor) parking space at a lower cost. Many cities are not willing to devote their energy to smart parking solution to discourage inhabitants from using their cars. Alternatively, an optimized transport solution to help people travel in cities, such as Citymapper, is commonly more supported by cities. In this case, Gaparking service provided by high motivated individuals can ease some drivers' headache. As such, Gaparking optimizes land use and reduces the need for public parking spaces. It also stimulates the growth of local economies and urban capacity with such a new and interesting (quasi) peer-to-peer business model.

Smart city: Smart parking systems manage real-time cities resources and geo-locally provides them to drivers. It involves on- and off-street parking management, shared parking, crowdsourced information, e-parking transactions, smartphone apps, data-interest matching, integration of existing and future platforms, join/leave of connected objects and cultural habits in different cities. That is why smart parking has been considered a promising inception and a leading paradigm of smart city [8]. Even though we have seen several successful smart

[33]European standard ETSI EN 302 895 – Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Local Dynamic Map (LDM)

[34]Named Data Network, a multi-campus research project for the future information-centric network. named-data.net

[35]ISO 21217 Communications Access for Land Mobiles (CALM) architecture

parking projects in San Francisco, Barcelona and Moscow, we shall not ignore the failed projects of Nice and Beijing. Nice gave up the smart parking solution because of the cultural habits of the French citizens. Differently, Beijing authorities did not consider the integration of diverse techniques. However, these failed cases do not dampen citizens' need for urban services. With the rise of open data and e-democracy, citizens expect all urban resources to be connected, informatized, and shared. The design of a smart city ecosystem inherits the open issues of smart parking, especially on urban mobility, which has a tremendous impact on resources status and cities capacities. Hence, it requires a complete consideration on different disciplines and human factors.

VII. Conclusion

Considering the urban population and traffic congestion increase and the reducing land, smart parking becomes a strategic issue to work on, not only in the research field but also from economic interests. The existing and ongoing works on smart parking are also very complicated and transdisciplinary. Cities always need to spend a long time on inspecting all the possible solutions and problems in other cities just to make a decision. In this paper, we presented a survey of the literature on smart parking solutions from academic, commercial and municipal perspectives. The many and varied earlier works, spanning out several disciplines, are closely linked and inseparable. To give a bird's-eye view of the literature, we introduced a smart parking ecosystem and proposed a comprehensive and thoughtful classification by identifying their functionalities and problematic focuses. We proposed three macro-themes: information collection, system deployment, and service dissemination. Then, we categorized and visualized the literature in very detailed tables and figures in each macro-theme. We explained and synthesized the main methodologies used in the existing works and gave a sketch of similar concepts. We also summarized their common goals and visions by solving the current parking difficulties. Next, we provided our engineering insights on the challenges of actual proposals and open questions. Our insights help cities think carefully what techniques to apply and what technologies to deploy. Moreover, cities can avoid repeating bad try and error processes and choose the most proper solution at the prospect of their sustainability and future extension. Our survey gives a comprehensive guide to research and commercial products by proposing beneficial smart parking solutions to cities. The main findings of the current state-of-the-art also throw out recommendations for future research on smart cities and future Internet architecture.

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