9 A Review of Smart Car Parking as IoT Systems

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Abstract

Car parking systems have been investigated extensively for minimizing the waste of time and traffic congestion due to vehicles cruising to park. Internet of Things (IoT) technologies such as sensing and networking have been utilized in car parking systems to provide connectivity of car parking components and to determine occupancy. Also, cooperation among vehicles for car parking based on vehicle-to-vehicle (V2V) communications has been investigated. However, interoperability, i.e., the ability for different systems to work together easily or to be used seamlessly, is one of the challenges for car parking systems, and for IoT applications in general. Car parking systems as part of city services can be owned by different stakeholders, which have different parking policies and use different car parking technologies. In this chapter, we outline conceptual architectures for parking systems, and highlight and discuss the challenges and approaches of interoperability in a range of smart car parking systems (implemented and proposed) in the literature.

Keywords

Car parking systems, Internet of Things (IoT), interoperability

9.1 Introduction

Increasing urbanization calls for governments to undertake “smart city” innovations to effectively manage and utilize urban resources (Bélissent et al., 2010). The smart city is aided by adopting Internet of Things (IoT) technologies (Atzori et al., 2010), e.g., connected embedded sensors/devices to monitor and manage urban resources, such as transportation systems and healthcare. IoT is defined by Gubbi et al. (2013) as a capability to access information from interconnected ubiquitous sensing and actuation devices via an integrated framework.

Parking is considered one of the common challenges in urban areas. It is estimated based on an IBM global survey that 20 minutes is the average time per day to find a car park (Gallivan, 2011). Furthermore, vehicles cruising to find car parking can contribute to traffic congestion, which, in turn, increase fuel consumption and air pollution as studied by Shoup (2006). Numerous car parking systems have been investigated. Smart car parking is a smart city application

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that facilitates locating parking spaces across the city, which can affect the time spent to arrive at a destination and the level of traffic congestion.

Moreover, given the different types of car parking systems, there is an issue of interoperability, which is the focus of this review. Unless online reservation is supported, information about parking spaces are generally siloed or available in a limited way (e.g., one has to come near to a parking center or an area to obtain partial availability information) so that wider scale (e.g., city-scale or suburb-scale) parking search, parking analysis, and parking coordination among vehicles, are not possible. Even a large shopping center with multiple car parks may not have integrated parking information for visitors, so that visitors have to manually navigate from one car park to another in search of spaces.

Indeed, the benefits of IoT for parking have been well articulated by Chandran et al. (2020). IoT smart parking solutions are being developed in some of the most populous countries of the world (e.g., Yadav and Prasad, 2019; Mufaqih et al., 2020).[1] Smart parking systems have been reviewed extensively (Diaz Ogás et al., 2020).

This chapter aims to review car parking systems, in particular IoT based solutions, i.e., solutions involving sensing, and thing-to-thing communications (e.g., V2X, including V2V based solutions), with a focus on conceptual architectural approaches and interoperability issues, i.e., the ability for different systems to work together easily or to be used seamlessly.

9.2 Car Parking Overview

Figure 9.1 describes a general architecture for car parking systems. There are three main stages: sensing parking, collecting and processing parking information, and distributing vehicles (e.g., via provided information, “nudges” or directed allocations) among the available parking spaces. The arrows represent the presence of data flows in a car parking system.

Firstly, the car parking space information is sent from car parking sensors, which are located in various geographic areas, to the database center, which can be centralized or distributed; parking information can be sent to the vehicles directly from sensors supported with wireless capability to the passing vehicles, or via local units which collect the parking information and broadcast the information to the vehicles (which is represented in the figure with the dashed arrow).

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[1] See also the NB-IoT parking system in China (`https://bit.ly/3lCsgbu` – GSMA, 2018, or `https://bit.ly/3lDdXn4` – China Telecom, 2021), and viewpoints from Indonesia (`https://bit.ly/3vLgG2t` – Shankar Gautamon, 2019) and India (`https://on.tcs.com/2QkWbcv` – Tata Consultancy Services, 2019).

After processing the car parking information, the next stage is allocating or distributing cars to parking spaces, which can be based on a fixed car parking infrastructure or messages sent directly to the moving vehicles.

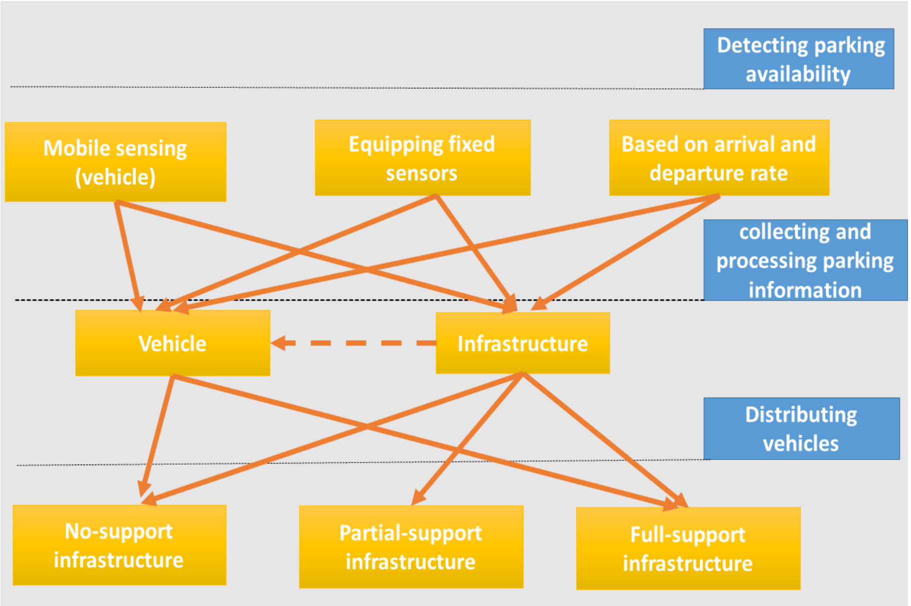

Figure 9.1: The conceptual architecture of a car parking system.

9.2.1 Sensing Parking Spaces

There are a variety of sensor technologies used to sense parking occupancy such as the inductive loop (Kianpisheh et al., 2012), RFID (Abdullah et al., 2013), ultrasonic sensing (Moguel et al., 2014), cameras (Bulan et al., 2013), and using magnetometers (Zoeter et al., 2014). The types of sensors used for smart car parking have been reviewed by Rupani and Doshi (2019) and Saleem et al. (2020). Chapter 10 in this book provides a comprehensive overview of methods for parking occupancy detection using sensors, and Chapter 11 discusses computer vision and deep learning techniques for parking space detection using CCTV cameras.

In addition, scanning parking space status (i.e., vacant/occupied) can be done by installing fixed sensors, which detect the parking occupancy of parking spaces within the sensor coverage, or mobile sensors, via sensors installed in vehicles to scan parking availability during vehicle cruising (Mathur et al., 2010).

Two approaches to determining car parking availability in car park lots have been considered. One, each car parking space is scanned by the equipped sensors and the other way is via determining the number of arrival and departure vehicles via the car parking gate. Sensor information can be collected and processed by parking lot owners or by cruising vehicles.

The parking spaces can either be on-street parking, which are managed mainly by the council, or off-street parking, which can be owned by different private stakeholders, and can adopt various car parking technologies. For example, Hammoudi et al. (2018) present a car parking assistance system using cameras for detecting car parking spaces with machine learning for image recognition. The collected data is stored in a central database. The allocated car parking space for a vehicle is selected based on distance to the vehicle's final destination and the traveling distance from the current vehicle location to the parking space; an A* algorithm is used to determine the shortest path.

Yan et al. (2011) use a vehicular network to inform the passing vehicles nearby the car park with a list of available car parking spots that can be detected and reserved by utilizing parking belts, using an infrared device for each parking spot. The system by Nawaz et al. (2013) exploits WiFi network signal characteristics to detect occupying and leaving parking spaces.

9.2.2 Processing Parking Information

A data-driven approach together with a number of connected car parking sensors to collect massive car parking information can be used to enhance the performance of the car parking system.

Rajabioun and Ioannou (2015) study improving the accuracy of presenting car parking information in a parking guidance and information (PGI) system across a city via a prediction algorithm based on the multivariate autoregressive model. Adewumi et al. (2014) use a particle swarm pattern searching algorithm, based on collected historical car parking data at a university in order to optimize allocation of car parking spaces. Nguyen et al. (2018) propose a car parking paradigm based on cloud computing that can collect big car parking data. The authors adopted Hadoop MapReduce in implementing an IoT car parking system that covers a sizable geographic area. The proposed car parking system is organized in layers to reduce the transmission and processing of information at the cloud server via clustering and processing at the fog-computing level.

9.2.3 Distributing Vehicles to Parking Spaces

In the process of distributing/allocating vehicles to parking spaces, there are three possible roles of the car park infrastructure which have been investigated: full support, partial support, and no-support.

- In *full-support infrastructure car parking*, the clients' role is restricted to sending parking requests and receiving the parking reservation tickets. The car parking infrastructure is responsible for selecting parking spaces.

- In *partial-support infrastructure car parking*, the car parking infrastructure provides the searching vehicles with supervised information that can affect the searching pattern. Such information includes providing vehicles with parking availability information, including variation in parking price policies. For example, suppose a car park area has few vacant parking spaces and a large number of vehicles inside are looking to park, then the car park infrastructure can provide the vehicles with parking offers with increasing parking prices to motivate some vehicles to search at alternative car park areas. It is then up to the vehicles to go to and find/select parking spaces.
- In the *no-support infrastructure car parking* perspective, the vehicles have to collect information and resolve the competition by themselves, so that the infrastructure has only a minor role or could even be completely absent.

9.3 Cloud and Agent-Based Architectures

In the previous section, we provided a general three-layered architecture for parking and outlined approaches in each of the layers. This section describes another dimension to the architecture of parking systems: centralized and decentralized schemes. In particular, we consider centralized car parking based cloud technologies, agent-based car parking systems and standardized vehicular cooperation.

9.3.1 Centralized and Cloud Based Car Parking Technologies

In this approach, the car parking paradigm is presented as a unified system to facilitate car parking, sensing parking occupancy status, analyzing the collected information, and interfacing with users through visualizing the parking availability or reserving parking based on a predefined plan. Cloud technologies have been used in this approach to connect car parking components which can be distributed in different areas.

For example, Sewagudde et al. (2016) introduced a car parking system for the Helsinki area, which manages parking permits, estimates parking availability and uses a parking payment plan. It applies LoRa (which is an acronym for Long range, low power wireless) technology to handle interoperability at the network level. In the same context, Lanza et al. (2016) introduce a field trial of car parking which presents the parking occupancy of indoor and outdoor spaces, for the ‘smart’ city of Santander downtown.

Ji et al. (2014) describe a cloud-based car parking system which consists of sensor, communication and application layers, using OSGi (Open Services Gateway initiative)-based Web and Android mobile devices for a car park at a university campus. Mainetti et al. (2015) propose a car parking system that helps drivers to the nearest available parking spaces with a payment method for users. The car parking system utilized 6LoWPAN and RFID sensors and applied the Constrained Application Protocol (CAP) to provide interoperability to access the sensing data of different sensors.

In the cloud-based smart parking solution of Atif et al. (2016), parking service providers are proposed which play the role of a broker, where parking lots can be advertised on a shared cloud platform. This can provide a degree of sharing across different parking systems, provided they agree to participate, and focuses the points of search for car park seekers.

Filtering the collected sensors' data in the car parking guidance system with the objective to save power by reducing the amount of information sent is studied by Alturki and Reiff-Marganiec (2017). Also, Alsafery et al. (2018) use a data fusion and filtering approach for a mobile app based smart parking solution.

9.3.2 Agent-Based Car Parking Systems

The main objective of this approach is to arrange agreements between clients and a number of car parking stakeholders. The car parking stakeholders are represented by local gateways responsible for managing their car parking spaces and communicating with the coordinator agent, which work as part of a middleware layer between car parking stakeholders and users.

In such an approach, in car park systems for cities, although the car parking operators have their own objectives, they are obligated to cooperate with the coordinator agent to provide an interface between different agents and promote reaching of, possibly automatically negotiated, agreements.

An example of a multi-agent system for parking is provided by Di Napoli et al. (2014), which deals with coordinating car parking in a city based on a manager agent. The manager agent negotiates with clients, which are represented by software agents installed in vehicles, and with car parking owners, via the Iterated Contract Net protocol.

Parkres[2] is a car parking system, based on the cloud computing paradigm, to facilitate car park reservations in a city for consumers. Consumers can register or log in to the system with a possibility of viewing nearer vacant car parking space, booking and paying, while considering traffic congestion levels. Parkres is based on an integration of IoT car parking ecosystems. It manages the variations among car parking technologies by adopting a gateway that can communicate

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[2] At `https://www.parkres.org`.

with local car parking systems and read different sensor data formats.

Jin et al. (2012) introduce a car parking system based on finding matches between clients and car parking operators' preferences using proposals via a coordinator agent. The coordinator agent sends a client request to the nominated car-parking operators, which are nearer to the client's detected destination. The car parking operators can invite the client based on the traffic condition, and the client can accept or reject the invitations.

Pham et al. (2015) study car park selection for drivers considering parking availability in the car parks and the distance to drivers' destination from car parks.

Yang et al. (2009) propose a parking guidance system to assist vehicles in searching, navigation and price negotiation. The work implements the FIPA (foundation for intelligent physical agents) architecture using multi agent messaging for interoperability among system components.

Kubler et al. (2016) provide a proof of concept of a smart parking framework to manage car parking at a sporting event (the FIFA World Cup 2022), with consideration of the variety of car parking areas' ownership. The design of the smart parking system is based on the Open Data Format (O-DF) and the Open Messaging Interface (O-MI) standard.

The car parking guidance system proposed by Wu et al. (2014) offers people a list of car parking areas with annotated parking availability and parking costs.

The variation in parking price policies among car parking areas is investigated by Chou et al. (2008), proposing agent coordination to assist drivers in finding optimum parking by bargaining on parking fees and computing the shortest path to the parking area. In the same vein, an auction mechanism is adopted by Kokolaki et al. (2014) to coordinate car parking based on parking fees. The agent-based approaches can be centralized or decentralized but are distributed.

9.3.3 Standardized Vehicle Cooperation for Car Parking

Connected vehicles is a promising technology that assists commuters by enabling adaptive vehicle routing based on traffic conditions, avoiding an incident or accident via notifications of unpredictable events, and helping to find parking via cooperation between vehicles and with car park infrastructure. For example, Aliedani and Loke (2018) study the benefits of autonomous vehicle cooperation to coordinate the drop-off problem without involving a centralized unit. Also, Aliedani and Loke (2019) evaluate the effect of cooperation for car parking, without help from infrastructure, of some vehicles on the searching time of non-cooperative vehicles (which can be a result of the inability to connect due to interoperability issues).

Datta et al. (2016) introduce an IoT framework to integrate with connected vehicles to deal with vehicle network characteristics of heterogeneity of devices (vehicles and sensors) and short-lived connections. The framework adopts edge computing, which means processing data near its source rather than sending to a distant central server. Also, the framework uses semantic web-based data formats to provide a uniform platform to describe and use data from different sources; also, Named Data Networking (NDN) is used for broadcasting data.

Vehicles need to interact with and potentially connect not just to other vehicles, but also motorcycles, bicycles, pedestrians, and other road-users, as well as with IoT services (including via Road-Side-Units), over Dedicated Short Range Networking (DSRC) or 5G-V2X networking. There is a requirement to use a unified approach or standards that enable vehicles from different automakers to communicate and utilize the received information.

Guerrero-Ibanez et al. (2015) summarize the requirements of connected vehicles:

- connected vehicle *technologies*, which concerns defining a platform for interoperating and developing new technologies,
- connected vehicle *applications*, which focus on developing applications that can use and process the received real-time information,
- connected vehicle *policy*, related to the institutional policies of the participants in local areas such departments of transportation, and carmakers.

Defining Internet of Vehicle standards has received a lot of attention and effort from international organizations such as the Institute of Electrical and Electronics Engineers (IEEE), Internet Engineering Task Force (IETF), and World Wide Web Consortium (Contreras-Castillo et al., 2018). The Society of Automotive Engineers (SAE) released a message set dictionary for standardizing messages exchanged in DSRC communications, such as intersection collision warnings, emergency vehicle alerts and vehicle status information can be shared.[3] There are also large European projects on cooperative-ITS including cooperative vehicles.[4] The European Telecommunication Standard Institute (ETSI) provided the EN 302 637-2 standard[5], which defined Cooperative Awareness Messages (CAMs). The message set dictionary, however, is not specific to parking applications using V2V communications. More work is required to develop message set dictionaries for cooperative parking.

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[3] At `https://www.sae.org/standardsdev/dsrc/` and in particular the message set dictionary SAE J2735 at `https://saemobilus.sae.org/content/j2735_200911`

[4] E.g., `http://c-mobile-project.eu/`

[5] `https://bit.ly/3ras0BK` – ETSI, 2021

9.4 Discussion and Open Issues on Interoperability

Smart car parking systems, as any large-scale IoT systems, have their issues with interoperability, which is defined by IEEE (Geraci et al., 1991) as “the ability of two or more systems or components to exchange information and to use the information that has been exchanged.” From this definition, there are two problems to be addressed in order to provide end-to-end parking services: connectivity among system components and using the collected information.

Four interoperability levels are defined by Noura et al. (2017) when designing IoT systems:

1. Device interoperability level concerns providing connection among devices utilizing various communication technologies. One common solution of this type of interoperability is adopting a gateway that support various communication standards such as Zigbee, Bluetooth, and Wi-Fi.
2. The network interoperability level concerns a mechanism for exchanging messages among devices, connecting via different networks and providing end to end connectivity. Cloud computing is one example of providing this interoperability level.
3. The syntactic interoperability level deals with the data format and data structure of the transferred data among devices, for instance, Web-based services support XML, and the JSON format for representing data.
4. The semantic interoperability level involves understanding shared data. For example, an ontology is a common approach, which can be a means for different parties to map between descriptions of common concepts.

The innovation of building an application that can manipulate data from multiple IoT systems (IoT silos) require the system’s ability to exchange both raw data (syntactic interoperability that requires defined common data format and encoding) and its meaning (semantic interoperability). In other words, it is required to set up an agreement among IoT systems about the exchange rules, that can be implemented either in building a uniform centralized system or designing a middleware layer across IoT systems.

In most work on car parking systems, the authors proposed their own car parking system as an isolated system, without considering the interoperability or cooperation with the surrounding car parking systems. From a vehicle perspective, generally, the vehicles on the street are manufactured by different companies and for various models, yielding heterogeneity in hardware and software components among vehicles, impacting on the value of vehicle applications in different aspects (safety, traffic management, and entertainments), especially with the absence of vehicular standardization. The U.S. Department of Transportation

(DoT) has sponsored a project on interoperability for commercial vehicles supported with dedicated short-range communication (DSRC) with regard to safety applications (LeBlanc and Belzowski, 2012). In the same vein, there are different car parking information formats and structures, which require interoperability across car parking ecosystems if large scale search and coordination of parking among vehicles is to happen.

All the approaches above, centralized (vehicle-to-infrastructure or vehicle-to-cloud based) or decentralized (i.e., V2V based), require interoperability at the networking and data layer, at least for messages to be exchanged and to be understood. Agent-level communication protocols and standardized message formats and protocols are needed for middleware level and application services level interoperability.

In centralized schemes, agreement on application service protocols will help integration of parking search and tracking services across different parking areas, perhaps managed by different companies; Web protocols provide a basic layer of interoperability but the data needs to be in a format understood by vehicles from different manufacturers.

In decentralized V2V schemes, agreement at the *level of message protocols and formats* is needed so that vehicles from different manufacturers can understand each other's messages; there is a greater degree of cooperation possible among vehicles, which calls for standardization of message formats and protocols at the *cooperation level* above the *networking level*. Interoperability is required for understanding sensor based messages (e.g., situation and status of vehicles and parking spaces), as well as for vehicular cooperation (e.g., if two or more vehicles are to negotiate about contended parking spaces). At the vehicle behavior level, for human-driven vehicles, once messages are received, they can be interpreted by the drivers who then control their vehicles accordingly. But with self-driving vehicles, the vehicle needs to interpret the messages and behave accordingly; there is a need for standards at the *behavioral level*, i.e., rules of conduct, e.g., that autonomous vehicles do not try to compete with each other aggressively on learning that certain parking areas are unoccupied. Then, at the *policy level*, car parking systems will need to be able to agree on policies for data sharing (given the potential competitive nature of different car parking companies), data integrity, and how vehicles are informed of parking availability.

Moreover, a mixed of centralized and decentralized multi-agent based approaches might be adopted by vehicles searching and negotiating for parking spaces; hence, in the absence of provider-level system interoperability, a possible approach to interoperability could be on the vehicle end, a market of vehicle apps, which aggregates information from other vehicles and multiple infrastructure parking systems, and translate the information into a common format for its own reasoning and manipulation (and perhaps also exchange such information with other vehicles).

In summary, referring back to Figure 9.1, interoperability can happen at all three layers of the architecture. For example, sensed information about parking spaces from different sensor systems can be shared for different systems to process. Processed (or summarized) information can be shared for different systems to act on. Decisions on allocations from different systems (or individual vehicle's intentions on where to park) can be shared, so that different systems or vehicles can coordinate among themselves on what to actually do.

Also, depending on the architecture and technology used, centralized cloud based or multiagent based, different mechanisms for interoperability are required, e.g., standardized RESTful APIs or data exchange formats for the former, and standardized agent-level protocols for the latter.

9.5 Conclusion

In this chapter, we discussed car parking systems with a focus on the interoperability issue. Car parking systems consist of connecting a number of IoT devices and ecosystems, which, if able to interoperate, could provide a city-scale solution for parking.

Various interoperability techniques are required to provide scalable car parking services, involving data semantics, interfacing with users, connectivity technologies and high-level cooperation and coordination of car parking among local car parking operators via a middleware layer. Brokerage among car parking providers can be considered, but requires cooperation, and third-party capture (e.g., via Low-Earth-Orbit satellites, drones or crowdsourcing) of available parking spaces can be implemented, but may be limited in the extent of services that can be provided (e.g., limited to availability checks, and no booking and payment services) as well as the timeliness of parking information received.

We have also noted the impact of vehicles' cooperation in reducing the time to park, while the inability of vehicles to cooperate can worsen a situation. Indeed, there is a need to define a unified parking solution to enable interoperability for parking, at multiple layers - at the network layer, at the device layer, at the high level data sharing level, and at the vehicle behavior-based cooperation level.

With automated vehicles, parking in some areas may be less of a priority, and drop-off zones then need to be considered. Analogous to search for parking spaces, searching for drop-off spaces in cities will be an upcoming challenge.

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