







Review

Smart Parking: A Literature Review from the Technological Perspective

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Abstract: The development and high growth of the Internet of Things (IoT) have improved quality of life and strengthened different areas in society. Many cities worldwide are looking forward to becoming smart. One of the most popular use cases in smart cities is the implementation of smart parking solutions, as they allow people to optimize time, reduce fuel consumption, and carbon dioxide emissions. Smart parking solutions have a defined architecture with particular components (sensors, communication protocols, and software solutions). Although there are only three components that compose a smart parking solution, it is important to mention that each component has many types that can be used in the deployment of these solutions. This paper identifies the most used types of every component and highlights usage trends in the established analysis period. It provides a complementary perspective and represents a very useful source of information. The scientific community could use this information to decide regarding the selection of types of components to implement a smart parking solution. For this purpose, herein we review several works related to smart parking solutions deployment. To achieve this goal, a semi-cyclic adaptation of the action research methodology combined with a systematic review is used to select papers related to the subject of study. The most relevant papers were reviewed to identify subcategories for each component; these classifications are presented in tables to mark the relevance of each paper accordingly. Trends of usage in terms of sensors, protocols and software solutions are analyzed and discussed in every section. In addition to the trends of usage, this paper determines a guide of complementary features from the type of components that should be considered when implementing a smart parking solution.

Keywords: smart parking; sensors; LPWAN; networking; smart cities

1. Introduction

The Internet of Things (IoT) has changed the habitual behavior of people, giving them many comfort improvements. This effect is allowing IoT solutions to grow rapidly [1]. Some research works have pointed out that the number of IoT devices connected to the Internet is increasing exponentially and will be nearly 77 billion by 2025 [2–7].

The Internet of Things (IoT) refers to the interconnection and exchange of data among devices/sensors [8], and most of IoT applications involve particular requirements such as long-reach, low data rate, low energy consumption, and profitability. Moreover, user network coverage may increase with cellular network technologies. However, cellular network technologies provide too much power to the devices, which is why IoT applications have driven wireless transmission technologies

such as Low-Power Wide-Area Network (LPWAN). This technology provides long range connections: approximately 10–40 km in rural areas and 1–5 km in urban areas [1,8].

Because of the growth of IoT and cloud systems, smart cities have great opportunities in terms of technological developments and accessibility, creating a revolution in some aspects of people's lives [9]. Smart city applications are being implemented in many countries, as they improve the quality of life of their citizens and help reduce environmental pollution by optimizing time and fuel consumption [10].

Smart parking is popular among smart cities, as described in articles of the industry [11,12]. These papers highlight that smart parking reduces congestion, increases revenue, has a pricing system that is adjusted based on the demand for availability on-peak hours, and reinforces traffic laws by using cameras to detect violators among others. Parking space search is one of the most important activities in a city, reaching up to 31% of ground usage in big cities [13]. On average, a vehicle is moving 10% of the time, and the rest of the time it remains stopped either temporarily or permanently, as mentioned in [14].

The common method used to find a parking space is manual as discussed by the authors of [15]. Approximately 30% of vehicles on the street are looking for parking, and the average time to do is ~7–8 min.

In cities with high vehicular congestion, finding an available parking spot can be a waste of time and resources. The authors of [16] found that, in areas such as Los Angeles, vehicles looking for parking spots produced over 730 tons of carbon dioxide and burnt 47,000 gallons of gas. The inconvenience created by the need for finding a parking slot causes some drivers to park in unauthorized zones, plus increasing vehicular congestion and carbon dioxide emissions. For instance, if drivers had access to a database containing information about parking spots in real-time, there would be more opportunities for selecting an appropriate route to a desired parking slot.

Autonomous vehicles are part of the smart parking initiative, as they consider mobility, fuel consumption, and journey time. Long-range Autonomous Valet Parking (LAVP) presents a novel approach, making an autonomous vehicle temporary park in a car park within an urban area. The authors of [17] state that the Scheduling Center is the core, as it coordinates the nearest route to a drop-off place and find the best car park. This approach will benefit users by providing a reservation system in a cost-effective manner. Other approaches, like [18], suggests that customers use an Android application to reserve a parking place in advance. In this solution, the authors propose using a trolley to move the car to the reserved spot by using a genetic algorithm.

There are several works that aim to provide a classification of some components of a smart parking solution [13,19–23]. First, Revathi and Dhulipala [19] denote a classification of parking systems, where the authors list several types that refer to assisted parking search (APS), Information Systems (IS), payment, automated parking, reservation, park assistant among others. Likewise, they list and describe different technologies used (sensors, image processing, and RFID). The authors have defined the categories mentioned above, but they have not considered reviewing if all the listed categories appear in recent works to determine a trend of usage.

Moreover, the authors of [13] perform an extensive review of several works that implement smart parking solutions. They have considered a 16-year period for the analysis. Authors have classified literature based on the categorization of functionalities getting three major: Information Collection (overview of sensing techniques), System Deployment (software system exploitation) and Service Dissemination (relationship between information and social features). Although they have extensively classified selected papers according to specific features and categories, they could have complemented their study by identifying a trend of usage for future use. The time threshold is very extensive and considered obsolete technology [24].

The authors of [20] adopted an approach that describes 13 tools, which are part of the smart parking solutions. Items that use any of these tools are marked inside the table. Although the classification process is like that proposed in our work, the research seeks to carry out implementations in open spaces.

Likewise, the authors of [23] execute a review of different works of parking management to identify the main requirements to implement a solution of that type. They listed several types of sensors and management systems in a table and mapped reviewed papers to such features. Finally, authors showed a proposed architecture for their system parking. This review does not describe a research method and considers several limited papers.

The authors of [21,22] base their research on specific characteristics of smart parking systems and, based on this, identify advantages and problems to understand ways of building architectures of a smart parking solution.

As described before, there are several approaches for classifying smart parking components. However, there is still work to do. We propose a different approach to classify such components that is intended to guide researchers on identifying top and novel trends related to sensors, software solutions, and networking by using an iterative research method. Our proposal focuses on recent works (after 2013) to point trends in technological use. Because of this review, additional sensor features have been described in a table for proper selection. Note that the sensors are the main point of these solutions, so it is important to choose one that adapts to the surrounding conditions. Our review sets forth technical insights to build smart parking solutions. Finally, the main findings of the current research draw a guide for future work in areas with little or no focus.

The rest of this paper is structured as follows. Section 2 shows the procedure of information retrieving used to find research papers related to smart parking solutions. Section 3 provides a classification of different used technologies where three distinct approaches have been identified used sensors, network usage, and service implementations. Section 4 highlights the most noticeable findings from the classification established in previous sections and the evaluation of statistics extracted from the survey. Section 5 suggests some features to consider before choosing a particular sensor. Finally, Section 6 presents the conclusions of the findings.

2. Research Methodology

The main purpose of this research is to analyze the tendency of components used within smart parking solutions from a technical perspective. The research method applied was a semicyclic process adapted and based on research action [25] and combined with a systematic review [26,27], which is composed of three main phases, each containing particular tasks that were executed during the proposed research, as shown in Figure 1.

The plan phase allowed defining search strings and research digital repositories. The perform review phase focused on adapting search strings for every repository, collect preliminary results, extract relevant information, and selecting candidate papers. Finally, a full review of the remaining document was performed to report relevant findings and results.

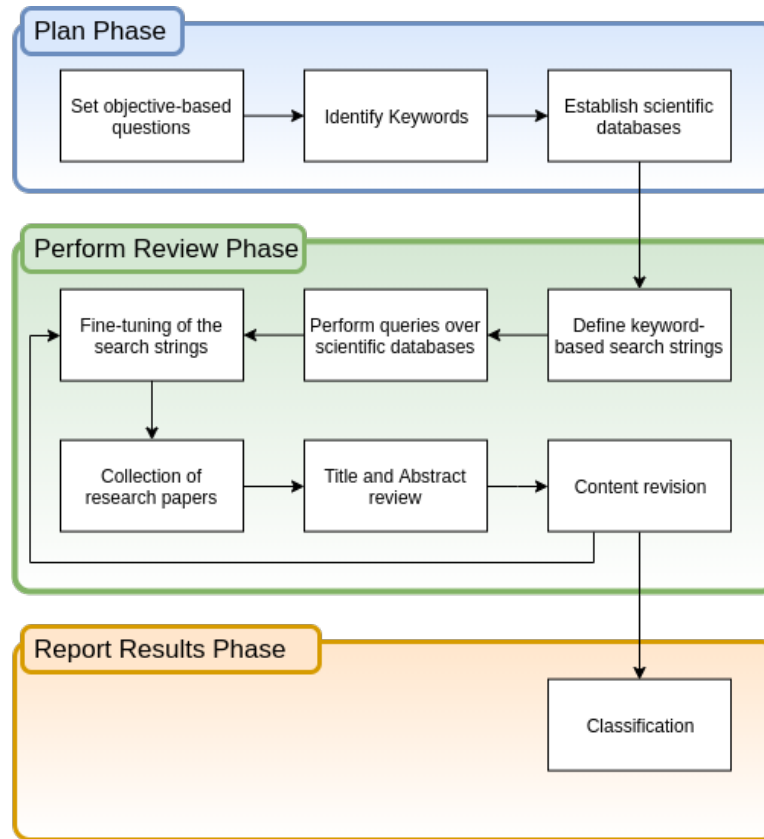


Figure 1. Detailed research method.

2.1. Plan Phase

This phase is related to the initial setup before starting a research procedure. Its main purpose is to narrow the scope and yield appropriate findings. First of all, the following research questions were established for this study .

- What are smart parking solutions that do not involve algorithms within their implementations?
- What systems or sensors are used to implement smart parking solutions?

The defined questions were related to our research goal, which was to review smart parking implementations from a technological perspective. With the above questions, the following keywords were identified; “smart”, “parkin”, “solution”, “sensors”, “systems”, and “algorithms”. Then, preliminary search strings such as “smart parking solutions” were defined. Those strings produced large results, and to reduce the number, it was necessary to use logical connectors to combine them with previous keywords. Besides, the word “algorithms” was excluded from search strings as the aim is to obtain information about technical aspects instead of prediction or optimization algorithms. Research databases were chosen to look for articles based on the defined search strings. The selected databases were ACM Digital Library, IEEE Xplore, Springer, and ScienceDirect. Finally, the defined search strings per digital repository are shown in Table 1.

Table 1. IEEE Xplore Digital Library, ScienceDirect, ACM Digital Library, and Springer query results.

IEEE Xplore Digital Library		ScienceDirect	
Search String	Results	Search String	Results
((((smart parking) AND solution) AND sensors) NOT algorithms)	49	smart parking solution and sensor	10
((((smart parking) AND systems) AND sensors) NOT algorithms)	172	smart parking systems and sensors	13
ACM Digital Library		Springer	
Search String	Results	Search String	Results
+smart +parking +solutions + sensors –algorithms	11	smart AND parking AND solutions AND sensors AND NOT (algorithms)	137
+smart +parking +sensors –algorithms	39	smart AND parking AND solutions AND system AND NOT (algorithms)	53

2.2. Perform Review Phase

During this phase, specific strings, which are defined in the previous phase, were searched into every digital research repository. To present the results a table was built. This table contains the name of the digital repository in its header (one for each one), the search string used, and the results obtained for every search string. The results obtained after performing such queries are shown in Table 1.

From the search results, only recent solutions were considered (after 2013) because technology becomes obsolete after 5 years, on average, as stated in [24].

First of all, with the aid of the result exporting feature provided by each scientific database repository, CSV was the format selected to export search results sets, as SpringerLink uses it by default. CSV documents containing search results were obtained. These files were later loaded in a tool to preview information such as title, authors, abstract and years. The tool called Zotero was used to execute such procedure. Zotero is an open source tool developed by a nonprofit entity. It was selected because it is able to process and deterge records in CSV and BIBTEX format. Likewise, it can generate “.bib” or “.sqlite” files, which are both supported by Mendeley. This tool allowed to conduct a first review of the found articles. Some of them had incomplete information, so they had to be filled manually. The most important field checked was DOI, as it contains their main identification. For the next step, a “.bib” file with information of all the reviewed articles was generated, and a private group for collaboration was created in Mendeley where these records were imported and stored. Then, PDF documents of the selected articles were retrieved and uploaded inside this tool. As a result, a subset of previously retrieved papers was obtained.

Finally, a protocol for discarding articles was followed. This protocol was executed manually, and it consisted on reviewing the title and the abstract of the papers which were collected from different digital repositories, to find keywords and brief details that might help to answer the research questions. If there were no terms or information related to the topic, such a paper is discarded. Then, the remaining papers were analyzed to identify if they were focused on the research topic. Finally, a second round or the process was performed to obtain a considerable number of papers for this research. A representation of the discarding protocol followed is shown in Figure 2.

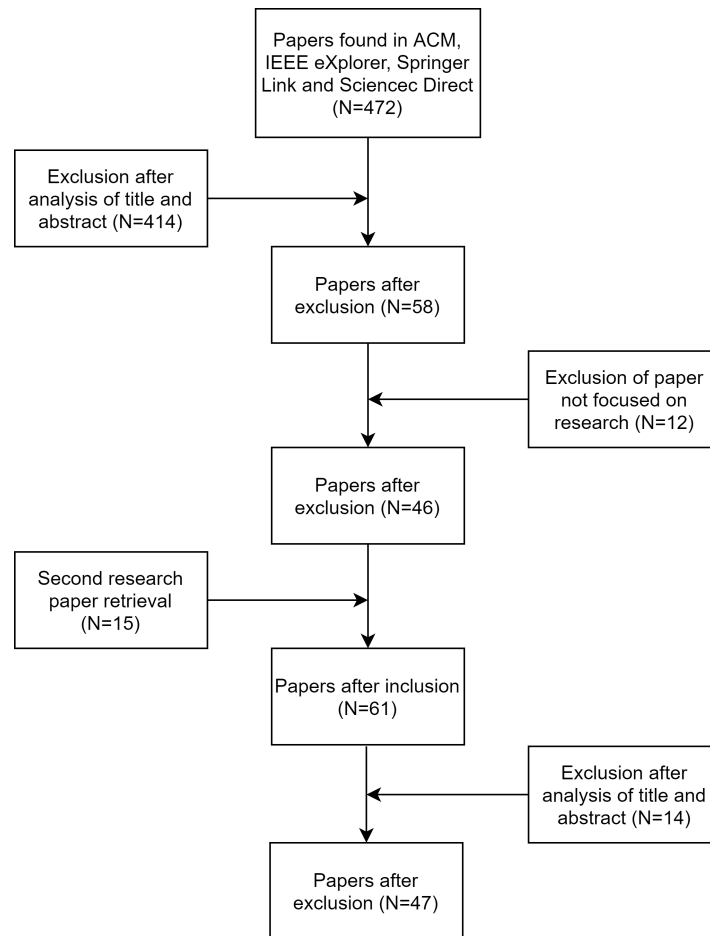


Figure 2. Paper reduction process.

During the first iteration, the first phase ended with a list of 484 articles, which included not relevant documents for this study. To filter relevant documents, titles and abstracts were read and analyzed. Filtering was performed by tagging these documents with a “YES” if it was useful and “NO” for irrelevant. During the first round, 414 papers were discarded, as they do not contain pertinent information. Then, from the remaining 58 papers, a full review was performed and turned out that 12 papers were not focused on the research topic.

A lack of documents was noticed and for this reason the process started a new iteration to retrieve more information using a new set of 12 keywords, adding “parking zone”, “vehicles”, “intelligent sensors”, which were introduced into previous search strings, giving 15 more papers to be reviewed; however, after the analysis, only 14 papers were chosen giving a total of 47 papers that were reviewed in depth.

However, to find a pronounced trend of smart parking implementations solutions and technologies, another iteration of the collection process was performed. In this round, search strings were readjusted to fulfill the needs found in the classification. Some added words were smart, parking, solution, sensors, systems, automatic, and parking, avoiding all the results related to algorithms. Adding new words to the search strings resulted in retrieving more articles related to the topic of research. The results are presented in a table with the same columnar structure as the previous one. (refer to Table 2).

Table 2. IEEE Xplore Digital Library, ScienceDirect, ACM Digital Library, and Springer query results for extra round.

IEEE Xplore Digital Library	
Search Strings	Results
(((((smart OR e OR automatic)AND parking) AND (systems OR solutions)) AND sensors)NOT algorithms)	24
ScienceDirect	
Search Strings	Results
smart parking solution and sensors	765
smart parking systems and sensors	904
automatic parking solution and sensors	911
automatic parking systems and sensors	1229
e-parking solution and sensors	1314
e-parking systems and sensors	1836
ACM Digital Library	
Search Strings	Result
+smart +parking +solutions –algorithms +sensors	26
+smart +parking +systems +sensors –algorithms	80
+automatic +parking +solutions –algorithms +sensors	2
+automatic +parking +systems +sensors –algorithms	80
+e +parking +solutions –algorithms +sensors	26
+e +parking +systems +sensors –algorithms	80
Springer Link	
Search Strings	Results
"smart parking" and solutions and sensors not algorithms	13
"smart parking" and solutions and systems not algorithms	15
"automatic parking" and solutions and sensors not algorithms	9
"automatic parking" and solutions and systems not algorithms	13
"e parking" and solutions and sensors not algorithms	87
"e parking" and solutions and systems not algorithms	392

The same discard process was applied. The first phase ended with 2819 articles, which contained documents that were not relevant to the investigation. A web platform called Ryan [28] was used to facilitate the classification work collectively. Once all the results were loaded, we proceeded to read and analyze the titles and abstracts of each paper. Then, in case the content is considered relevant for the classification, a "Maybe" label tag was used to mark such papers. An "Exclude" label tag was used to mark irrelevant for papers for this research. In the first round, after the discarding process, 104 papers were obtained. Finally, after the elimination and classification process, 40 additional elements were obtained, giving a complete set of 87 articles used for this survey.

2.3. Report Results Phase

In this last step of the research methodology, all findings and results were documented. Those findings were used to build the next section which is the core part of this research. Besides, further findings were analyzed and discussed to set up and identify tendencies in regards to the use of technological components of smart parking solutions.

3. Smart Parking Solutions

Vehicle production has grown considerably in the last 30 years as pointed out in [29]. Having more vehicles around the streets implies more fuel and time consumption and a growing demand for parking

spaces. These problems can be addressed by smart parking solutions. They are one of the most popular use cases within the concept of smart city and seek to improve the quality life cycle of a city [29].

The architecture of smart parking solutions is mainly represented by three elements: sensors, networking protocols, and software solutions. Sensors are the most important element as they collect information and feed the whole system. Networking protocols are governed by a gateway that implements wireless IoT protocols and connect sensors to the software systems. Finally, software solutions ensure that information is available for everyone through some sort of service. For instance, people can use this information to view heat maps of zones with the highest parking slots occupancy [30].

To implement a smart parking solution, several technological components are involved, such as sensors, networking infrastructure, and software solutions, among others. Regarding smart parking architectures, there are several works that have been presented by industry and the scientific community. Some of them focus on the solution, others on the algorithms, software, or systems, whereas others briefly state the technology of the sensors. For instance, the authors of [31] propose an approach based on artificial intelligence (agents) to find available spots. In [32], the authors discuss different approaches to implement Smart Parking solutions; it considers the whole ecosystem of such type of solutions which basically involves sensors, gateway selection, edge processing, and data center analysis. For its part, the authors of [33] depict an architecture totally based on ZigBee technology. Moreover, the authors of [9] suggest artificial intelligence for optimizing park search, but barely specify the technical details of implementation, such as specific protocols or sensor types. Likewise, the work proposed in [34], shows the use of Bluetooth Low Energy (BLE) as a protocol for connecting sensors and gateways. Bluetooth is a wireless protocol that supports connection between end-devices. The BLE version consumes very few energy and is part of the wireless IoT stack protocol. Other solutions, like those in [35], suggest the use of IR sensors for its architecture. Smartphones are also considered in these solutions particularly to find available spaces [36]. Considering the aforementioned, it can be seen that there are no international standards or base architectures defined for implementing smart parking systems. Therefore, it is necessary to analyze how different components are being used as well as identify tendencies in regards to their use in order to implement a smart parking solution.

Smart parking solutions were developed with many technologies and approaches; therefore, a classification will be performed considering the established points. In this case, three different perspectives were selected: sensors, network infrastructure, and service provided to users. The aforementioned perspectives were selected based on the importance given in [37].

3.1. Types of Sensors

Regarding transportation planning and traffic management, the most important topic is parking [38]. Nowadays, determining the availability of a parking is difficult if there are no elements that allow to identify if it is vacant or not. The intention of the sensors is to solve this problem and sense its availability and communicate to parking system through a network gateway. Although the sensors solve the detection problem, a large number of these are required to exercise adequate control over a given space. There are sensors that do not cover large spaces, and therefore one per spot is required. Therefore, the larger the space, the greater the quantity and therefore a higher cost. Note that for the sensors to be well used, they require technological infrastructure for the transport of the data. This implies the installation of data networks whether these are cellular or gateway based [13,39]. Also, in cases where wireless communication is not feasible, a structured cable approach to collect information must be in place. Weather conditions are a limitation that need to be considered and supported by sensors. Even though there are alternatives for using other sensors like smartphones or cameras in large spaces, there are security concerns that need to be addressed first [13].

Sensors are the most important component of a smart parking system as they feed system with valuable data. Therefore, they need to provide reliability and require very little or almost no maintenance. Sensors define the network technology and the mechanism for sending data

to the backhand (smart parking system). They should not depend on human interaction to provide information about the environment. Energy consumption must be minimal and if possible and have its own self-sustaining source of energy (i.e., solar energy). Indeed, the inclusion of Microelectromechanical System (MEMS) sensors will help reduce size, power consumption, cost, and extend performance and lifetime [40]. This evolution will lead to sensors with multiple capabilities rather than specific types.

Information retrieval is one of the most important aspects of smart parking solutions, and for this process, a great variety of sensors offered in the market can be used. Among the different types of sensors for smart parking, the most common ones are ultrasonic, magnetometers, cameras (used for detecting vehicles and free slots), cellular sensors, and radars [41]. A summary of the type of sensors used on the reviewed papers is shown in Table 3.

This table is structured as follows. First, the reference to the reviewed paper is given. Then, all types of sensors identified during the review are listed as columns. Any paper that uses a type of sensor is marked with a black bullet “●” under any column that applies; otherwise, a “-” is placed. The column “Other” refers to a type of sensor that is not clearly specified in the reviewed paper. The following table only contains papers that detail the use of any sensor.

Table 3. Sensor classification.

Reference	Sensor Type						
	Camera	Ultrasonic	Cellular Sensors	Infrared	Radar	Other	Magnetometer
[15]	-	●	-	-	-	-	-
[30]	-	-	●	-	-	-	●
[41]	-	-	-	-	-	-	●
[42]	-	●	-	-	-	-	-
[43]	-	●	-	-	-	-	-
[44]	-	●	-	-	-	-	-
[45]	●	-	-	-	-	-	-
[46]	-	-	-	-	-	-	●
[47]	●	-	-	-	-	-	-
[48]	-	●	-	-	●	-	-
[49]	●	●	-	-	-	-	-
[50]	-	●	-	-	-	-	-
[51]	●	●	-	-	●	-	-
[52]	-	-	-	●	-	-	-
[53]	-	-	-	●	-	-	-
[54]	-	-	●	-	-	-	-
[55]	-	●	-	-	-	-	-
[56]	●	-	-	-	-	-	-
[57]	-	-	-	-	●	-	-
[58]	●	-	-	-	-	-	-
[59]	-	-	●	-	-	-	-

Table 3. Cont.

Reference	Sensor Type						
	Camera	Ultrasonic	Cellular Sensors	Infrared	Radar	Other	Magnetometer
[60]	-	-	●	-	-	-	-
[61]	-	-	●	-	-	-	-
[62]	●	●	-	-	-	-	-
[63]	●	-	-	-	-	-	-
[64]	-	●	-	-	-	-	-
[65]	-	●	-	-	-	-	-
[66]	-	-	●	-	-	-	-
[67]	-	-	●	-	-	-	-
[68]	-	-	●	-	-	-	-
[69]	-	-	●	-	-	-	-
[70]	-	-	-	-	-	-	●
[71]	-	-	-	●	-	-	-
[72]	-	●	-	-	-	-	-
[73]	●	-	-	-	-	-	-
[74]	●	-	-	-	-	-	-
[75]	-	-	-	-	-	●	-

From the research performed, it can be seen that among the scientific community the most used sensors are ultrasonic, whereas cameras and smartphones (accelerometer, gyroscope and magnetometer) are in second and third place, respectively. This can be attributed to the fact that ultrasonic sensors can detect with greater precision the depth and thickness of surfaces in addition to working at high frequency, having high sensitivity and high power.

The classification listed in the previous table shows that sensors are not always combined to produce smart parking solutions. Some proposals, like that in [51], do not specify a type of sensor, but the authors assume that a vehicle might contain cameras, ultrasonic, and radar sensors. Other approaches, like [52], specify that a TSOP 1738 infrared sensor is in charge of detecting the presence or absence of a vehicle. All in all, the combination of sensors will certainly produce quality solution since the input data will come from many sources that have different features. The sensor in each reviewed work aims to cover the need to gather information depending on the characteristics of the environment. A brief explanation of how sensors are used is described below.

3.1.1. Camera

An approach for information retrieval is by using the video cameras of parking lots, which have the ability to process images by themselves without the aid of external devices or algorithms. This allows controlling many vehicles with one piece of equipment. This approach also leads to the creation of a new part of the system focused on receiving and processing those images. For this scenario, a common technique is the use of wide-angle cameras together with a classification algorithm to detect the parking lines and establish the status of a space, as described in [73]. Moreover, an approach that involves rearward cameras is described in [63]. The main purpose of this work is to help drivers parking in a selected spot by using a touch screen. This approach is composed of three steps: bird's-eye view construction, guideline recognition, and identification of parking separating lines. The authors propose a novel approach to operate with real-time images. This semiautomatic initiative has good performance and does not require hardware modifications according to the authors.

Likewise, it is possible to use common outdoor cameras to improve the accuracy of detection by training the algorithm with images taken in different weather conditions [74]. The authors also describe another solution, which involves storing an image of the area taken from a camera in a database together with the coordinates of each space, and then comparing the stored image with the images that are sent in real-time to establish if a parking lot has been occupied or not. In this scenario, it is important to consider that when video cameras are used outside, efficiency can be reduced due to weather conditions, even if the training phase was performed with images of several weather conditions. However, when it comes to indoor parking lots, this can be a viable option since images are not affected by weather conditions. Images are stored into a database along with the coordinates of each one of the parking lots, and can be compared with images that are being sent on real-time to determine if a slot is occupied or not.

There are other solutions where users are involved to establish parking slots occupancy through cameras installed in their vehicles as stated in [56]. This proposal pretends to help drivers to avoid parking in illegal places by offering a real-time system. The authors use event recorders to collect information. The technique used to determine vacancy of a space is static image streaming. In this system, drivers generate a parking request through a mobile Android application, and the response contains location of the place. The mobile application also collects information through the camera. The system collects and process images and videos to determine and suggest an available parking space.

Nowadays, cameras are becoming an essential element of vehicles, roads and smartphones. They capture real-time information with more features than other sensors. Although they depend on a robust backend and appropriate weather to process data and metadata for producing results, they are a good source of information.

3.1.2. Ultrasonic Sensors

These sensors emit waves on a determined frequency and measure the distance between itself and the object that stands in its wave's path. Due to its effectiveness and precision, a great quantity of smart parking solutions have been proposed based on this technology [13]. These sensors are used to detect a parking lot status (free or occupied). There are different types of technologies that are used in previous works to transmit and process data generated from sensors. For instance, placing a sensor on a high position of the place and sending data to a raspberry through Wi-Fi [42]. Also, through a cable, such as in [55], or connecting it to an Arduino that is part of a XBee network [64,65], it is possible to connect a sensor to a HTTP server that also allows to verify parking lot availability [48]. Similarly, a solution proposed the use of a wireless network called Xmesh [15]. Furthermore, along with the advancement of technology, new implementations involve LPWAN technologies such as LoRa that connect sensors for the transmission of the parking space status [72].

Ultrasonic sensors are implemented one to one which means that there is one sensor for every parking slot. Additionally, it is important to mention that these sensors are low cost and their detection accuracy is high.

3.1.3. Cellular Sensors

Mobile phones have become a tool of great use in people's daily activities, and so they have been widely used in systems for smart parking. One of the approaches involves scanning WiFi networks so as to establish the person that is in the parking lot both when the vehicle is being parked and when the user is coming back to it. The mobile phone's accelerometer and gyroscope determine if the car is moving when the user is inside it [66]. In the same way, another approach involves establishing an exact position by creating a location profile [67]. Both approaches are used to determine if client parks his vehicle in a parking slot in a specific area that could be an indoor or outdoor parking lot.

GPS sensors are also used as an application that sends the user's location and allows the system to create a heat map with the acquired information showing free and unavailable parking slots [30].

Also, the use of QR codes that are meant to be scanned by users' mobile phones, would be helpful for finding their parking spaces and their information would be sent to the solution's server so the status can be updated, allowing users to acquire their vehicles location easily in case they need it [60]. Using this type of sensors gives more possibilities in terms of using sensors, but creates the need of a study to determine which combination is the best to detect a person inside a car and when the car was left in a parking slot.

Smartphones include sensors like accelerometer, gyroscope and magnetometer. These devices are part of our daily life and widely used. Drivers are carrying them all the time so they could be used as a great source of information. The data they produce comes georeferenced which helps identify specific places in a map. In short, a smartphone represents a sensor with many embedded sources of information that also allows drivers to view information collected through different smart parking systems.

3.1.4. Infrared

The use of infrared sensors with ZigBee technology on an Arduino Uno is also considered as an option, as shown in [71]. This schema is only applicable for a single parking lot.

Infrared sensors can measure the distance between two objects by measuring the time it takes for an emitted signal to be reflected by an object. In [53], the authors used a light detection and ranging optical sensor (LIDAR) to measure the distance between a car and an object next to it. Also, the combined this sensor with a GPS receiver to determine the speed of a vehicle in a particular pair of geographic coordinates and a web camera to track tests. All the information is then sent to a Raspberry Pi connected to the cloud for further data processing and analyses. Finally, the obtained candidate measurements to determine if a parking slot was empty or not.

3.1.5. Radar Sensors

The usage of 2D images generated by a radar sensor, along with artificial intelligence, can be translated into the substitution of video cameras, allowing the establishment of a parking slot status through a convolutional neural network training that has the radar information as input data and throws slots status as results [57]. These sensors give the possibility to use one powerful device to cover a great number of parking slots. However, it requires a system that can process all those signals.

3.1.6. Others

Another approach is to use geomagnetic vehicle detectors (which are similar to magnetometers), which are specifically used for Smart Parking purposes as mentioned in [75]. This approach can be used in one parking slot only. This sensor uses advanced magnetic sensor and algorithms for signal detection to detect vehicle presence.

3.1.7. Magnetometers

These sensors measure the magnetic field around them in order to perceive big metallic objects, e.g., vehicles [13]. For instance, sensors used to collect information in San Francisco, allow to establish a demand profile for parking lots, giving more importance to occupancy on parking lots that are being monitored compared to the ones that are not [70].

Magnetic loop detectors maintain a resemblance with magnetometers; the difference being that a change occurs in the loop when an object passes through it, the magnetic field is altered, and the detection is performed [41]. These are presented as a feasible option to retrieve parking lot information, and in the presented solution it comes along with RFID so an on-street parking reservation can be performed, allowing the sensor to recognize the slot occupancy and confirms the vehicle identity using the RFID information [46].

Like the previous sensors, magnetometers offer the same functions and also help to know that the object placed near the sensor is metallic, it helps to differentiate common objects from cars.

3.2. Software Solutions

This component is of vital importance for the systems as it determines how to handle obtained information. Either only for storage and registration, to build a prediction system to improve the allocation and reservation of parking spaces, or an online system with which the end user can interact. Without software components, Smart Parking systems would be limited to perform very primitive tasks.

Software solutions are the central core for processing information collected by sensors and disseminate results to end-users of other systems. The purpose of every solution relies on the needs defined by stakeholders [13,29]. Software solutions should not act only as a repository because its information help to reduce time, fuel, and money. Its architecture has to be robust enough to deal with great amount of information and provide services to a large scale of users. To achieve this, they could be deployed over cloud infrastructures either private or public. These solutions combined with a good mobile application are an important work tool because they allow users to perform certain tasks such as reserving parking spaces, or finding the nearest parking lot at a specific time of day. Software solutions should provide real-time information, as it is key for drivers to make decisions.

Data that resides in software solutions represent a useful tool mainly for governments that are working to improve urban development and mobility. Data could show points of high concentration and suggest alternatives for users that are nearby. This information could be used to predict parking availability in places with no sensors or poor communication coverage. From a commercial perspective this information is a gold box as service points could be established near sites with high vehicular congestion. Also, construction companies could benefit from this information to determine where to build more parking buildings or to increase the capacity of current ones.

Software solutions are essential and must handle information to benefit cities and users. In the future, they should contain all these features: information management, analysis and prediction, and e-parking services.

3.2.1. Information Management

One of the most sought after solutions in the parking systems is the way information is handled, either for data storage processing to improve the operation of the system itself, or to decide how and what information will be presented to the user.

In [15], a basic Parking Guidance and Information (PGI) structure is proposed together with a Driver Request Processing Center and a Smart Parking Allocation Center. These are the systems responsible for the collection of driver requests and real-time information, such as the location of the vehicle and the allocation of parking spaces according to previously stored requests, respectively. It interacts with the Parking Resource Management Center, which is in charge of real-time information retrieval and exposes, either through Internet, Variable Message Signs (VMS), mobile, or applications, similarly to the solution presented in [46], where services are handled and presented only through a web page. In both cases, the communication of the sensors with applications and user interactions is considered, so as to make reservations or check the availability of parking services.

Many of the reviewed solutions handle three states for a parking slot: free, busy, and reserved. Also, there are cases in which intermediate states are handled to facilitate user guidance. An application of the management of the information network of parking spaces facilitates the monitoring of illegal parking actions, as in [76], where the authorities control vehicles that exceed the authorized parking time limit or that have not paid for the space, and also use it to change the parking costs depending on the area in which it is located, the time, or the day they are being used.

There are also three modeled architectures as in [54]. In the first one, the availability of parking spaces is detected. The second, handles queries of availability performed by the client according to its location and the need thereof. The last, shows the parking information in real-time to the user. Other approaches, such as that in [77], include control by the authorities plus a user application which is used to verify the location of the parking space. It also includes a secure storage system where

payment information is saved and an application for the authorities responsible of road control to verify inappropriate use of parking spaces or identify spaces that have not been paid.

Many of the solutions found, emphasize that a cloud storage system is required either to centralize information in case that there are many different parking lot service providers, as described in [78]. It will allow to connect several service providers to a common request cloud so that users can consume information from all of them. On the other hand, this schema could be used only to store parking data such as parking time, user information and locations as shown in [42].

3.2.2. Prediction

Prediction systems have also been taken into consideration thanks to the collection of information by sensors. These systems can be improved by integrating a prediction of availability of parking spaces and improving routes according to the possible flow of vehicles. This will lead to decrease parking time and pollution generated during the search process.

Whether there are free spaces or routes to them, there are prediction systems such as [15] that use a system to find the best slot for each user depending on the distance from the destination and the cost that is willing to tolerate, repeating the cycle and updating the variables in case the user does not accept the allocated slot.

There are also reservation systems, as in [79], that focus on current traffic statistics to decide a route and a parking space to be reserved according to the user's current needs. It also takes into account the spaces that are available or are likely to be available at the time of user's arrival.

3.2.3. E-Parking

Once the information has been got, the most common way to present such information is via software solutions over the Internet, either through a mobile application or a web browser. In these solutions, users can interact with different deployed parking services.

An example of this interaction is reserving parking spaces, as mentioned in [15]. The system allocates a parking space and the user decides whether it is appropriate to continue with the reservation. Likewise, in [46], a similar system is described, where the user is in charge of selecting the parking lot to reserve from a list of available spaces. Moreover, in other solutions these parking slots can be reserved with days of anticipation or if the user requests it, they can keep changing as long as a better one is found based on the user requirements as shown in [80].

In other cases, e.g., in [48], the user was allowed to decide whether he/she wants a manual or automatic allocation of the parking spaces through a mobile application. This approach has the particularity of verifying user's identity when arriving and leaving the parking space to provide a certain level of security to the system.

All the papers reviewed within this scope have been marked according to the sub category where they fall based on the solution type that has been implemented. A summary of such classification is listed in Table 4.

The following table has four different columns; each of them represents a type of Software Solution that was identified from the review. Selected columns were: Information Management, Prediction, E-Parking, and None. No column shows specification details on the type of solution built. Then, only the papers that described a particular type of solution were considered and marked with a black bullet "●" under the corresponding column; otherwise, an empty space was left.

Table 4. Papers according to software solution types.

Reference	Information Management	Prediction	E-Parking	None
[15]	●	●	●	
[16]				●
[30]	●			
[36]				●
[37]				●
[41]				●
[42]	●			
[43]	●			
[44]	●	●	●	
[45]	●		●	
[46]	●		●	
[47]	●	●		
[48]	●		●	
[49]	●		●	
[50]				●
[51]				●
[52]	●		●	
[53]				●
[54]	●			
[55]	●			
[56]		●	●	
[57]	●			
[58]				●
[59]				●
[60]	●			
[62]	●		●	
[63]				●
[64]	●	●		
[65]				●
[66]	●		●	
[67]				●
[68]				●
[70]	●		●	
[71]				●
[72]				
[73]				●
[74]				●

Table 4. Cont.

Reference	Information Management	Prediction	E-Parking	None
[75]	●			
[76]	●			
[77]	●			
[78]	●			
[79]		●		
[80]			●	
[81]	●			
[82]	●			
[83]				●
[84]				●
[85]				●
[86]				●
[87]	●		●	
[88]	●			
[89]				●
[90]				●
[91]				●
[92]	●			
[93]	●			
[94]		●		
[95]	●			
[96]				●
[97]				●
[98]				●
[99]	●			
[100]				●
[101]				●
[102]	●	●	●	
[103]				●
[104]	●	●	●	
[105]	●			
[106]				●
[107]				●
[108]				●
[109]	●		●	
[110]				●
[111]	●			
[23]				●

Table 4. Cont.

Reference	Information Management	Prediction	E-Parking	None
[112]	●		●	
[113]				●
[114]				●
[115]	●			
[116]				●
[117]				●
[118]				●
[119]	●			

The results shown in Table 4 point out that most of smart parking software solutions among the scientific community are designed and proposed for information management. However, E-Parking software solutions are gaining adherents, which is probably because this type of solutions provide services besides information. Anyhow, software solutions are vital to properly handle and disseminate information collected and provide services to final users.

3.3. Networking

Networking protocols are key to pass information from sensors to smart parking system otherwise it would be chaotic to connect to every sensor in place for retrieving its data. In smart parking solutions there are two types of network protocols (one for users and one for sensors). In some cases, sensors and users might use the same protocol. However, user protocols consume more power and require having Internet connectivity. On the other hand, most sensor protocols does not connect directly to the Internet, they have to pass through a gateway sometimes (i.e., LoRa, ZigBee, and NB-IoT). This gateway is in charge of translating a Wireless IoT protocol to a TCP/IP based.

The deployment of smart parking solution demands a network architecture infrastructure able to support hundreds of thousands of devices connected transmitting every certain time. This topology must consider short-range and long-range communications for connecting sensors to gateways and then to software solutions. These network implementations have to focus on deploying wireless IoT protocols and mesh networks to cover wider spaces and allow sensors to transmit even if gateway node fails.

Networking in smart parking have to be aligned to low energy consumption, minimum delay, and reliable throughput. There are initiatives in places to improve networking for smart parking, as described in [39].

The usage of several communication solutions has been proposed over the reviewed research papers. On this context, the solutions were classified into two major categories as shown on Figure 3. First of all, the “sensor network” category describes network architecture and protocols applied to sensor communication. Then, the “User Network” category describes protocols used to send useful information to the end user. This classification was based on [13] and the noticeable trend in the use of wireless network technologies for sensor communication. Finally, the “Vehicle Network” category was not considered, due to the lack of research papers containing information about those networks; therefore, that category was discarded.

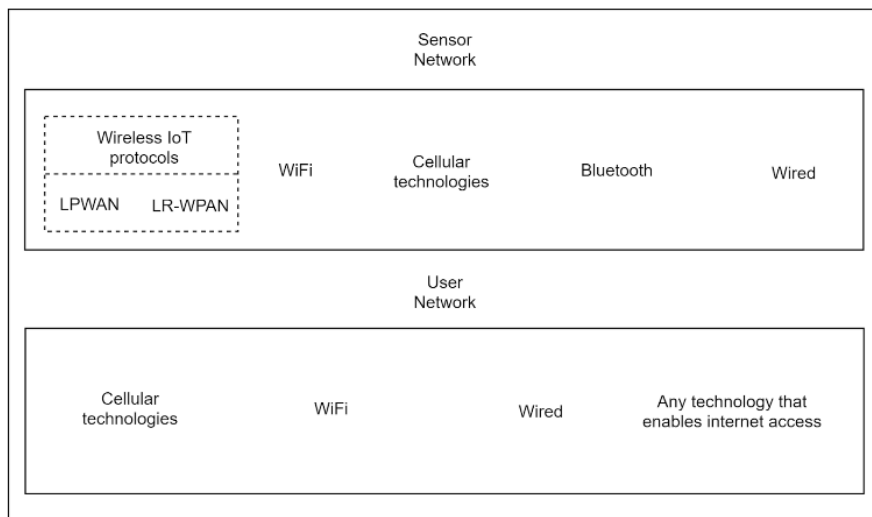


Figure 3. Network design distribution.

3.3.1. Sensor Network

This category includes the most used technologies on the deployment of applications. The most important subcategories are Wireless protocols (LPWAN and LR-WPAN protocols like LoRa, NB-IoT, and ZigBee), WiFi, and Cellular technologies (3G/4G). Other subcategories include Bluetooth and other wired technologies (i.e., Ethernet, USB, and serial communications).

The following table (Table 5) contains two major columns—sensor network and user network—which represent the type of networking technology used by a sensor or user to connect to the infrastructure of a Smart Parking Solution. Previous columns have been divided into types of networking connectivity. Wireless protocol indicates that a wireless IoT protocol was described in the paper reviewed, if so, the “Specific Protocol” column is filled with the name of the used protocol. Then, if a paper matches a specific column, black bullet “●” appears otherwise a blank space. Only the papers that specified a type of networking technology were considered in this table.

3.3.2. User Network

User Network classification is divided into four subcategories. The first category is called “any technology that enables internet access”; however, research papers did not describe protocols used, but established that any device with internet access could receive data from a system. The second and third category embraces “only WiFi” and “only Cellular technologies (3G/4G)”, respectively. The last category covers wired technologies that can be anywhere from Ethernet, USB, serial communications, among others. All the papers reviewed in this category have been classified according to the subcategories described before. Such classification is shown in Table 5.

From Table 5, it can be seen that Wireless IoT Protocols are mostly used among research community for connecting sensors with gateways along with the combination of Wi-Fi and 3G/4G to send information over a TCP/IP network. On the other hand, for User Network known technologies are used either to connect, manage, or consume information from smart parking solutions.

Table 5. Sensor network and user network classification.

Reference	Sensor Network						User Network				
	Wireless IoT Protocol	Specific Protocol	WiFi	3G/4G	Bluetooth	Wired	Not Defined	3G/4G	WiFi	Wired	Bluetooth
[15]	●	ZigBee									●
[16]							●	●			
[30]				●				●			
[36]				●				●			
[37]	●	IEEE 802.15.4									●
[41]							●				●
[42]			●						●		
[43]	●	ZigBee (XBee)									●
[44]											
[45]	●	ZigBee						●	●		
[46]							●		●		
[47]							●				●
[48]			●						●		
[49]							●				●
[50]				●							●
[51]							●				●
[52]	●	ZigBee							●		
[53]		LTE-IEEE 802.11p		●							●
[54]						●			●		
[55]			●			●					●
[56]							●	●	●		
[57]			●						●		
[58]							●				●
[59]			●						●		
[60]							●				●
[62]							●				●
[63]							●				●
[64]	●	ZigBee									●
[65]	●	ZigBee		●					●		
[66]			●						●		
[67]			●	●							●
[68]							●				●
[70]							●				●
[71]	●	ZigBee							●		
[72]	●	LoRaWAN							●		
[73]						●					●

Table 5. Cont.

Reference	Sensor Network					User Network					
	Wireless IoT Protocol	Specific Protocol	WiFi	3G/4G	Bluetooth	Wired	Not Defined	3G/4G	WiFi	Wired	Bluetooth
[108]			●			●		●	●		
[109]							●				●
[110]				●				●			
[111]							●				●
[23]							●				●
[112]	●	ZigBee	●		●				●		
[113]							●				●
[114]							●				●
[115]							●				●
[116]							●				●
[117]							●				●
[118]							●				●
[119]							●				●
[120]							●				●

4. Discussion

Considering the research papers retrieved and analyzed for this survey and taking into account the distribution of published smart parking lot papers per year, as shown in Figure 4, an increasing trend can be realized, starting in 2013 where a small increase can be seen compared to previous years. In 2014, a notable amount of research papers related to the analyzed subject were published and lit up the increasing interest in Smart Parking Lots. Even though in 2015 there was an unexpected decrease, in 2016, it retakes its peak with a stable trend from 2017 to 2018. This trend shows that the chosen topic is of interest and strengthens what is described in industry reports [11,12].

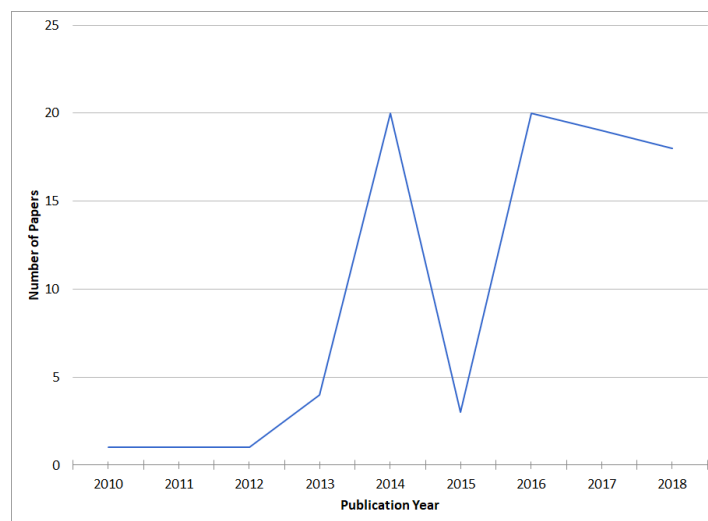


Figure 4. Research paper distribution.

4.1. Types of Sensors

Among research papers that were found relevant, only 58% presented detailed information about kinds of sensors used. These focused on proposing a solution without no real implementation. Distribution regarding sensors found on research papers is shown in Figure 5.

The results of the most used types of sensors are displayed in Figure 5. This graphic shows that ultrasonic sensors are the most popular among research community, reaching nearly 35% from the reviewed papers. On the other hand, cameras with almost 26% are the second type of sensor used for designing or implementing smart parking solutions. Third, although technically smartphones can include some of the sensor capabilities mentioned above, they have a 23% of use within the research work revised.

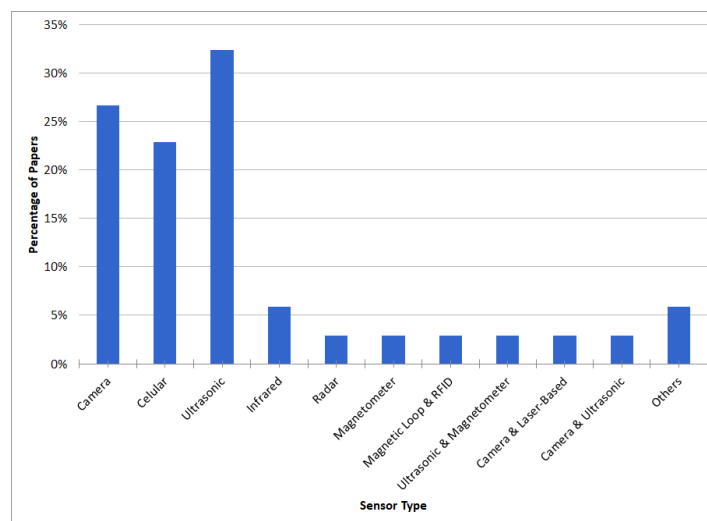


Figure 5. Sensor type.

As appreciated, ultrasonic sensors are the most used category, and this tendency has reached a maximum that is still maintained, as shown in Figure 6. The highest peaks in relation to the use of ultrasonic sensors border 23% in 2014 and 2017. The graph shows an increasing trend in the use of these sensors over time. This might be because of their easy installation and management, meaning that a great variety of devices that can be connected either through wired or wireless media.

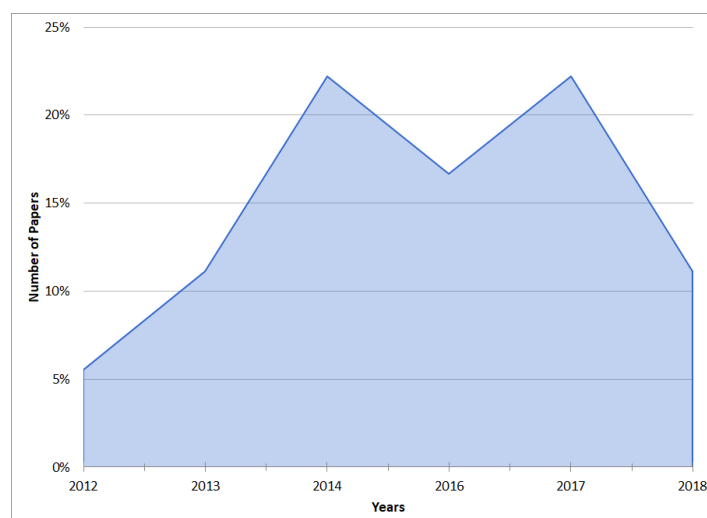


Figure 6. Ultrasonic sensor usage.

Using video cameras and image processing algorithms can become a complicated process for training and detection; although, in overcoming these difficulties, it is possible to cover a great area with only one device, resulting in a convenient solution. These do not need an existing infrastructure, resulting in a simpler implementation. Figure 7 shows the trend regarding camera usage. The trend in using cameras remained in the last two years after a substantial drop. However, because of the percentage of papers dealing with the subject of the sensors and taking into account the trends, it can be established that the importance of establishing a sensor has been decreasing to focus on the development of generic solutions that can make use of a wireless sensor either. The scientific community might focus on the approach of providing an infrastructure model that could be adapted to specific needs.

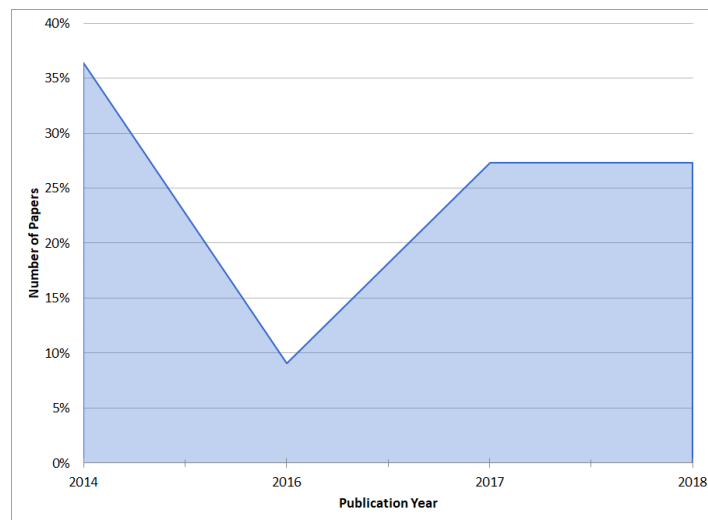


Figure 7. Camera usage.

4.2. Software Solutions

After finishing the review of all the retrieved research papers, as shown in Figure 8, it was noticed that 51% of the reviews did not mention any kind of solution, as most of them just focused on sensing methods and different algorithms used for smart parking.

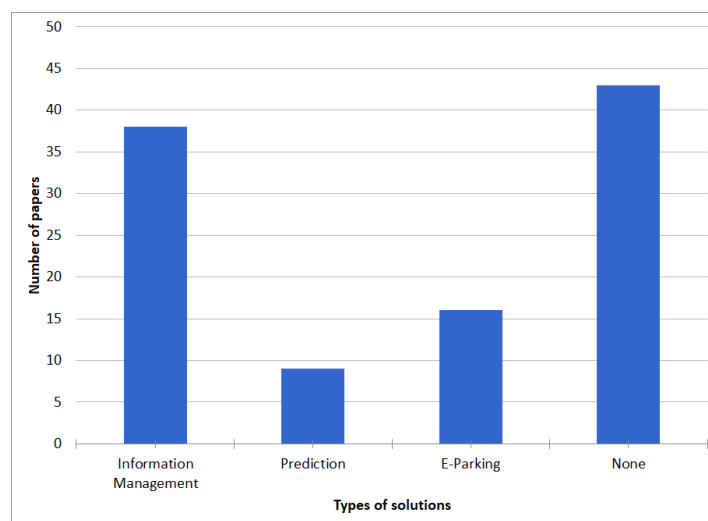


Figure 8. Software Solutions of smart parking.

Among those that contain a detailed description of how these were implemented, only a 45% have a detailed explanation of how parking information was handled, being the classification with

most samples. Almost all of these research papers explained the modules and structure that raw data had to pass through from sensors up until how that resulting information was presented to final users. Also, some of them mentioned that a cloud storage is an important factor for Smart Parking implementations, as shown in [42], because stored information would be accessed by users via the Internet.

The most used software solution is Information Management with 38% among the revised papers. From the reviewed work it can be seen that the proposed or designed software solutions are looking forward to handle information rather than providing a whole set of services as in E-Parking solutions.

The second most mentioned classification is E-Parking, where most solutions focus on the interaction between users and parking slot reservations, and one of the main issues is that users could go after the same space as mentioned in [56]. We also found that the information is presented through this medium but the interaction that users can have with it is not shown in great detail apart from the visualization and reservation of the parking spaces.

Finally, implementing algorithms for prediction of reservation and assignment of parking spaces only reaches ~11% of the research papers.

4.3. Networking

Regarding sensor networks, 40% of the selected research papers did not specify using a certain protocol or networking solution, or their scope was focused on presenting a survey or some algorithm. From the remaining papers, 85% proposed a wireless implementation using WiFi, Bluetooth, mobile communication technologies, or wireless IoT protocols; sometimes implemented as ZigBee, LoRa, or NB-IoT. Most of the solutions using wireless technologies justify this because of the reduced cost of deploying this network architecture compared to wired solutions [13,121].

With the aforementioned, we can say that wireless IoT protocols and WiFi technologies are the preferred ones for sensor communication, taking 51% and 31% of the classified solutions, respectively, in contrast to 15% corresponding to 3G and 4G technologies. Whereas, on the user side technologies there are several, but all of them are focused on the web. Anyhow, network technologies used to reach end users can be 3G/4G, WiFi, cable, etc., as long as they can provide access to the Internet.

Analyzing wireless IoT protocols usage per year (Figure 9), we can see an increase in the usage of these technologies from 2013 to 2014 with a slight decrease in 2017 and a final increase for 2018. A stable trend in the usage of wireless IoT technologies for smart parking applications exists.

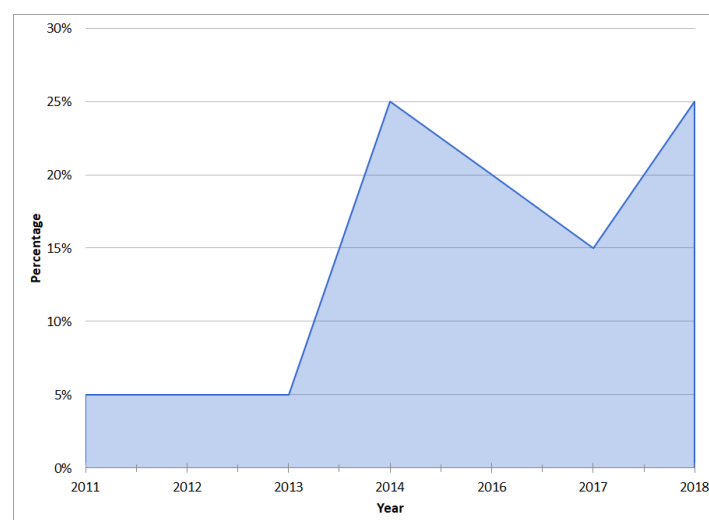


Figure 9. Wireless IoT protocol usage per year.

On wireless protocol usage, the most used technology is ZigBee, followed by LoRa and NB-IoT, sharing second place. Of all the classified articles in the wireless IoT protocols category, 25% did

not specify the technology used and only mentioned the standard IEEE 802.15.4 which is the base of several protocols of such a type. This trends appear in Figure 10. From the research performed it can be seen that Zigbee is the most used protocol for connecting sensors with 60%. In second place, IEEE 802.15.4 reaches 25%. There are others, like LoRa and NB-IoT, that reach 5% for every one.

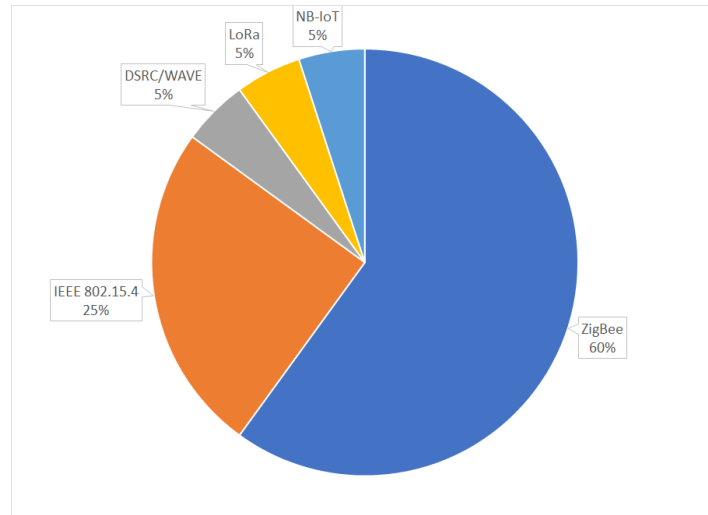


Figure 10. Wireless Internet of Things (IoT) protocol usage distribution.

The increase in using wireless IoT protocols over WiFi and Cellular technologies occurs because wireless IoT protocols are designed with IoT applications in mind. Most of them have less power consumption compared to cellular technologies and a bigger range compared to WiFi, but less bandwidth overall according to a survey by R. Sinha [3]. Another advantage of some wireless IoT technologies is using nonlicensed bands, making operations costs cheaper.

Network design was more focused on LR-WPAN (i.e., ZigBee), with 71% technologies, compared to LPWAN (i.e., LoRaWan), with 29% as shown in Figure 11. Although both LPWAN and LR-WPAN are based on the IEEE 802.15.4 standard, the key differences between them are the operation range. This is a deciding factor at the moment of choosing one or the other depending on the application to be deployed according to [122].

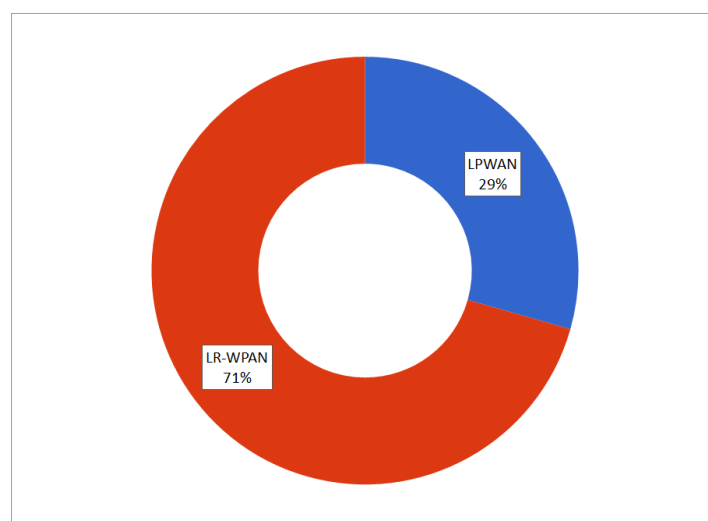


Figure 11. Network design distribution.

In terms of user networks, most of the implementations are focused on web-enabled devices like smartphones and tables, so the most common networking solution for this part was WiFi and

mobile technologies. This also includes other devices that can be connected by wire, taking 67% of the classified solutions. Only 25% of the solutions focus on mobile devices only. This is not surprising because of the common use of mobile and web applications nowadays.

For most of the analyzed papers, security topics were not taken into account in terms of network technologies, despite security vulnerabilities on wireless IoT protocols, such as LoRaWAN [123]. In some research papers, this was unnecessary because some proposed solutions were done via wired technologies or were focused on algorithms and architectures for smart parking implementations. There are many cases where researchers did not implement additional security for the use of secure enough technologies like WiFi or data was not even meant to be protected.

Another problem found during the networking analysis was the lack of a method for choosing a networking solution. For example, [75] picks NB-IoT to solve the disadvantages presented by ZigBee and Bluetooth solutions. The authors in [64] use ZigBee without justification. However, to choose the right solution an alternative is proposed in [122].

Finally, some trends of usage over time appear in Figure 12. It shows the evolution of different wireless IoT protocols. Although Figure 9 showed a high concentration in ZigBee, the highest index of use appears in 2018 and another high point in the graph appears in 2014, whereas the other years maintain a constant value. This implies that ZigBee is gaining popularity for its technical benefits and is being used in smart parking solutions.

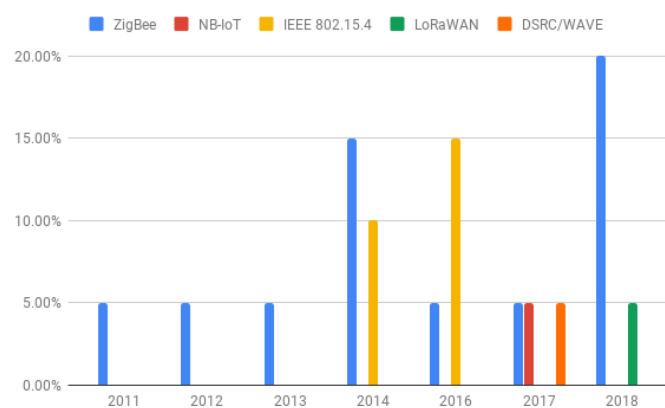


Figure 12. Detailed wireless IoT protocol usage per year.

IEEE802.15.4 has a high concentration of use in Figure 9, but in this figure, it is not happening. The protocol had its use boom in 2014 and 2016. This implies that this protocol has not caused the impact to stay.

Although NB-IoT is also a highly used protocol in the industry and is as new as LoRa, the current figure does not reflect it. This may be because NB-IoT has strengths applicable to other fields of smart initiatives.

Last but not least, a protocol that attracts attention in the graph is LoRa, with its highest index point in 2018. It is important to emphasize that this protocol was officially born in 2015 and had security improvements in 2017. This behavior gives to understand that he is a candidate to gain popularity since it has many followers in other smart initiatives for its technical and security benefits.

5. Sensor Selection Strategy

As a part of the conducted research, several features have been identified in regarding different sensors reviewed before. The features extracted from the review are invasive, ease of installation, sensor per slot, and detection autonomy. First, the invasive characteristic has to do with the possibility that the installation of a sensor produces modifications or alterations of physical or logical nature in the beneficiaries of its service (i.e., adding extra out-of-the-box equipment to a vehicle to detect that a

slot is empty or not or giving a card to a user for accessing a slot). Second, ease of installation refers to the action of placing a sensor somewhere, sometimes it is required to use complex infrastructure like structured cabling, electrical connections, aerial gutters, among others, whereas there are other sensors that only require being buried under the ground. Then, the amount of sensors per slot is something important as there are some cases where one sensor is used per slot, and the accuracy level is higher to determine if it is free or not whilst there are other types, such as cameras, which use only one device to cover a wide area but the level of accuracy is low compared to the previously mentioned types. Finally, detection autonomy is the ability of a sensor to determine by itself if the slot is free or occupied. With cameras, they need extra elements or processing to determine the availability of a slot. The following Table 6 summarizes the different sensors reviewed during this research in terms of the features identified and described in this section. Sensors that comply with the feature listed are marked with “yes” otherwise a “no” will appear. This table intendeds to guide readers to choose a sensor based on the conditions described and that are part of smart parking solutions.

Table 6. Sensor selection strategy.

Sensor Type	Features				
	Invasive	Ease of Installation	One Sensor per Slot	Several Slots per Sensor	Detection Autonomy
Camera	No	No	No	Yes	No
Ultrasonic	No	No	Yes	No	Yes
Smartphone sensors	No	Yes	Yes	No	Yes
Magnetic Loop	No	Yes	Yes	No	No
RFID	Yes	No	Yes	No	Yes
Infrared	No	No	Yes	No	Yes
Radar	No	Yes	No	Yes	No
Laser-based	No	No	Yes	No	Yes
Magnetometer	No	Yes	Yes	No	Yes

The table described before shows that RFID is an invasive sensor, as a card or an RFID tag must be given to a user or installed in a vehicle to access a parking lot and determine if it is free or not. Although a camera covers a wide area of slots, it cannot detect availability by itself. Its detection functionality is tied to an image processing algorithm or the combination of another sensor to determine the availability of a particular slot.

In terms of networking, there are some considerations that need to be addressed when implementing a smart parking solution. First of all, coverage is important, as some protocols have a limited range (long and short). This limitation affects the number of gateways that are going to be deployed. Network topology plays an important role since a star topology will require that every node connects to a particular gateway, this affects reliability of the network. In a mesh topology, end-nodes can communicate between each other, providing redundant connection paths. If a mesh network scales, their reliability and performance improves. Finally, although most short-range and LPWAN protocols are free there are others like NB-IoT which requires a license for use. In summary, the following features have been identified: Protocol type, range, network topology, and spectrum. The following table describes features of some protocols that need to be considered before choosing a network protocol (see Table 7)

When it comes to software solutions, everything starts from the perspective of the data. At this point, stakeholders decide whether the system will provide services (i.e., reservation of spaces) or if it will analyze data in a descriptive or predictive manner. However, other considerations that must be taken into account are information lifetime, concurrency level, and availability level. The features

listed above will allow the required hardware infrastructure to be sized appropriately. With these data you can make the last decision that has to do with using a public or private cloud service; this is usually given by national regulations.

Table 7. Sensor networking features.

Features				
Protocol	Protocol Type	Range	Network Topology	Spectrum
LoRaWAN	Long-Range	5 km (urban) 20 km (rural)	Star	Free
NB-IoT	Long-Range	1 km (urban) 10 km (rural)	Star	Licensed
ZigBee	Short-Range	10 m–100 m	Mesh	Free
IEEE802.15.4	Short-Range	10 m	Mesh	Free

6. Conclusions

Based on the reviewed literature, there are a few solutions where LPWAN technologies are used for smart parking implementations, but the most reviewed research papers used LR-WPAN technologies, specifically, ZigBee. Anyhow, there is a trend in using LPWAN solutions as shown in the findings discussed before.

There are several types of sensors that can deploy a smart parking solution. The conditions that dictate using one or another sensor are tied to technological advantages, budget, type of solution, and weather. Our research identified that in terms of technological advantages, there are four particular features that should be considered, those are: invasive, ease of installation, sensors per slot and detection autonomy. Those features would help to identify the ideal sensor to be used in any smart parking system.

Network security implementations are not a concern at the moment of the deployment of a solution, although it could become an issue for the potential misuse of the transmitted information and the reliability of the system. From the client/end-user perspective, the great majority of solutions focused on devices capable of connecting to the Internet because it allows the system to expand to a great variety of gadgets. Sensors used for retrieving information in smart parking solutions must have real-time and automatic data collection. As a result, almost every implementation described in the reviewed papers used some kind of sensor. Although smart parking systems generate a lot of data, several implementations did not implement or propose prediction algorithms from the retrieved data.

In terms of future work, one way to improve this survey is to increase the number of reviewed papers and focus on a specific system to narrow the field. The review focused more on smart parking implementations capable of working on street and inside. In addition, we plan to perform a comparative analysis about the effectiveness of LPWAN or LR-WPAN on Smart Parking to propose a formal method to select a sensor based on its technical features and the aim pursued.

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