An Intelligent Parking Sharing System for Green and Smart Cities based IoT

Adel Mounir Said[1], Ahmed E. Kamal[2], and Hossam Afifi[3]

[1] National Telecommunication Institute-NTI, Egypt; [2] Iowa State University, USA;
[3] Telecom SudParis, Saclay, France
amounir@nti.sci.eg, kamal@iastate.edu, hossam.afifi@telecom-sudparis.eu

***Abstract*— Today car drivers struggle to find a free parking space for their cars. It is considered a big challenge specially in large cities and in rush hours. Many studies considered this problem and how it influences our life. This increases emissions and energy consumption and wastes people's times as they try to find a free space for their cars. People normally become exhausted all over the day to reach their destination which causes stress and make them lose their temper. This would have a bad impact on the quality of life and economy.**

Based on the above, today people expect technology to address this problem and hence find a suitable solution to end the suffering of motorists. On the other hand, IoT is a promising platform for providing unusual applications for helping people and provide them a better way to manage their day's lives.

This work proposes a solution for a green intelligent parking system based on IoT. This solution is supported by proposing the game theory mathematical model. Game theory is used to model a reservation system of the proposed car parking solution. This work tackles the main problems facing car drivers to find available car parking spaces. These problems include: the parking fees, how far the car park from the car drivers destinations and hence the amount of walking, and the parking duration. Moreover, the proposed solution encourages companies and householders to offer their own parking stalls and/or driveways for renting in the unused times. From one hand, this will help on providing more parking lots specially in the dense traffic areas. On the other hand, the owners will get a revenue of their unused assets. Therefore, this work proposes a solution to parking problems by providing affordable parking lots based on the choice of the car driver that is relatively close to the destination. As a result of that, there will not be wasting of time or energy, frustration and panic will be reduced, fewer traffic jams, and consequently a green environment and a better quality of life.

***Index Terms*— Smart Parking, IoT, Game Theory.**

I. INTRODUCTION

Car parking has become a frustrating problem and a big challenge for almost all cities all over the world. Cruising to find an available parking lot wastes not only time and fuel, but may also cause traffic congestion and driver frustration. According to a new study [1], UK drivers spend what is equivalent to four days yearly trying to find parking for their cars. In 2007 [2], there was a study about finding a parking lot in downtown Los Angles. The wasted fuel is 47,000 gasoline gallons which is equivalent to 38 trips around the world which pollutes the world by about 730 tons of CO_2 emission. This is expected to increase with the increase in the number of gasoline powered cars.

One of the best solutions is to check if there are free parking lots in the vicinity of a visiting area before the expected arrival. But it is possible that it will be taken by another driver as the number of parking spots is limited in big cities. Therefore, there is a need for a friendly system capable of locating the best places suitable for parking, especially in times of congestion and it will be a great help if it can also allow reservation for cars based on the estimated arrival and departure times.

Now the world is migrating to automated life environment aspect of implementing smart cities. The smart cities' activities such as smart home, smart buildings, intelligent transportation systems (ITS), and industrial automation planed to be connected and controlled through the emerging Internet of things (IoT). IoT constitutes the platform for connecting everything to the on-line world. It has a great benefit of using sensors of low cost and low power communication technologies [3].

This paper proposes a frame work for an intelligent parking sharing system based on the five layers IoT model [4]. An analytical model is proposed to validate the system performance. This proposed model is promising to control all the parking areas and provide many added values. The proposed system semantic design will authorize companies and individuals to rent their parking lots through it, which is considered an added value to utilize the free parking lots everywhere in the vicinity. This proposal increases the capacity of the system in terms of the number of controlled parking areas and subsequently the served customers. Accordingly, the proposed solution flexibility decreases the service failure probability specially in rush hours which could occurs due to not finding a suitable car space fitting the driver's requirements. This is in addition to profiting individuals acting as parking lot operators which may motivate other operators to participate. On the other hand, individuals and private corporations may share their parking areas, hence profiting. This will increase the system capacity by providing more parking locations specially in congested areas and cities. Customers therefore need not go early to their events to find parking spots.

Different tariff plans may provide more flexibility and encourage people to use the proposed intelligent parking system. One of the most important benefits from this system is to provide a green environment and reduce traffic jams. This model proposes also to use GPS navigation to guide the drivers to the parking areas, and then indoor localization guides inside the parking area to reach the lot assigned to that customer.

The proposed system, as shown in Fig. 1, is built over a well established IoT architecture, which is the five layers suite as will be discussed in detail in Section III.

As a conclusion, this work presents four contributions as follows:

- Proposed a green solution for an intelligent parking system based on IoT that saves time and energy.
- Proposed the use of game theory to model the reservation system
- A solution for solving the parking congestion by proposing a parking sharing system that is based on encouraging companies and householders to offer their own parking stalls and/or driveways for renting in the unused times and hence get a financial revenue.
- Providing parking lots based on the car driver requirement which is based on one of two options; a relatively close to the destination or reasonable fare.

The organization of the paper is as follows. Section II introduces a review of the related works. Section III introduces the System architecture, while Section IV introduces the analytical model. Section V contains the analytical and simulation results. Finally, Section VI contains the conclusions and the future work.

II. Related Works

Since car parking became a big challenge specially in congested cities, smart car parking started to be addressed by many researchers.

In [5], authors introduced a smart parking system for reserving a parking lot based on a decision taken by solving a mixed integer linear problem. This solution is based on proposing an arbitrary system framework collecting the drivers requests and the available free parking lots to match between them. Authors built their criteria based on a combination of the parking spot, and the destination of the driver and the parking cost.

The work of [6] proposed a very simple model for managing car parking. There are parking spots each equipped by a wireless sensor network (WSN) that sends its status to a database server. From the driver side, there is a web server which can be accessed by the driver to allocating a free parking spot. Finding the suitable parking spot depends on the driver, as this model doesn't provide advice about parking spots.

Authors of [7] proposed a smart parking system for reserving a parking spot using a mobile software application. This system consists of five modules that interact together to guide the driver for reserving a free parking spot and optimizing the distance between the parking area and the destination of the driver.

The work of [8] proposed a smart parking system by considering it as a linear assignment problem. Cars are considered as jobs and the agents are the parking lots. First, the model collects the driver requests in a queue and then applies an off-line processing to guide the driver to the nearest free parking area. Also, in [3], authors performed data clustering to detect the real-time parking lots availability. This was based on using Support Vector Machine (SVM) as a classifier algorithm. A parking data set was collected for San Francesco city. In these works [3,8], authors proposed only a mathematical model to manage car parking without proposing a system architecture that uses the proposed model.

In [9], authors proposed a smart parking system based on the 3 layer IoT model architecture [10] and cloud computing. The IoT model considers the system cloud computing servers to be the middleware which is placed in the application layer. As it is well known, the 3 layer IoT model does not cover all the data transfer technologies available. Also, in the 3-layers IoT model there is no middleware layer. The middleware is only found in the 5 layer IoT model.

Authors in [10] proposed a system architecture for smart parking using IoT platform and cloud based database server. Parking areas are represented as network nodes with each having a neighboring table containing information about the neighbor nodes with a direct connection. Every network node is responsible of handling its parking lots, and in case there is no available spot, it directs the next car to the nearest parking area based on the neighboring table. A driver is responsible of choosing the suitable parking lot from the available areas. The model does not propose the control of the parking system to be in a centralized server. Moreover, there is no on-line reservation, so the information about a free lot anywhere is not guaranteed.

The work of [11] proposed a smart parking model based on cloud computing combined with an IoT platform to estimate or find the free parking lots. The model is built based on integration between middleware function, cloud based function, learning from the real-time data sets, and finally modeling a collaborative business process by a domain-specific language. This work is missing a validation part either by simulation or analytically. Moreover, there is no description of the system process steps or a use case of how it will work.

In [12] the authors proposed a simple prototype for a smart parking model based on using a USB camera to monitor the parking lots and a database server containing the information about the free parking spots. Drivers would be able to login through a mobile application to search for a free parking lot by themselves. As obvious, the system is not based on electing the best parking spot as the drivers may not be familiar with the parking area. Also, errors may occur due to the use of CCTV systems in addition to the high cost of such systems.

In the work of [13], authors proposed to use ITS to overcome the problems of finding a parking slot. For that, they proposed to use wireless sensors in the parking slots to indicate whether these slots are free or not. These sensors are connected to a gateway which provides the connection to a server. Car drivers are allowed to contact the server to check the availability of a free parking spot. This work does not provide a tool for reserving the parking spot. Moreover, it is not guaranteed to check for a free location before the vehicle's arrival, and the spot could be taken by another car. Moreover, checking the availability of a free site when the driver reaches his destination is impractical and time consuming specially if there is no available parking spots there. In this case, the car driver has to search again in another area close to his distention and will face the same result again if that slot is taken by another car.

In [14], authors proposed using GS1 standards for developing a smart parking system. Users can check online if there are free parking lots in a certain area and in the surroundings through an android application. This application also provides the ticket price and guiding directions from Google maps. However, this system doesn't provide reservation system and searching mechanism for a best parking choice.

In [15], using augmented reality in conjunction with video navigation has been proposed. The parking slot available is identified using captured scenes for the parking lot. Hence, a server provide directions to the nearest free available slot to the driver. This work can be called a closed system, as drivers will search inside a certain parking lot and not in all areas.

The work of [16] proposed using the historical parking data of a given location to predict the availability of parking spots and hence announce this availability. As this work is based on prediction, authors relied on machine learning to achieve their results. This work may get good results in some cases but that depends on the data sets used and its accuracy. Moreover, this model doesn't provide a control system to reserve the available parking lots or at least guide the drivers to its location. Also, the model will not be valid in many situations such as in the presence of events and with the change of the weather conditions.

Authors in [17] proposed to monitor the parking spots by exploiting the roadside cameras. They used Neural Network to build their model and a mobile application to ease finding the available parking spots by the drivers. First, this model doesn't include the indoor parking spots. Also, if a driver found a free parking spot, there is no guarantee it will free for him until his reach. This model can be used to calculate occupancy ratio and needs a reservation system.

In the work of [18], authors proposed a prototype system based IoT for managing the parking spot of a university campus. This system monitors the parking spots availability and facilitate reserving it through a web application. This model maybe fulfils the driver requirements for private places. In public places, the solution should provide navigation guide. The solution should have a control of all the parking lots in the vicinity, so can provide the suitable park fits the driver's requirements.

In [19], authors proposed a platform called VICINITY uses load sharing for smart parking and the different house smart appliances. This platform is based on IoT and renewable energy resources. It proposed to integrate the parking management with the energy management system to provide overall supervision and regulation. This solution provides the available parking slots that can be used for charging the electric vehicles and its charging price. This solution can't be considered a dedicated control system for parking especially it considers the parking spots for electric vehicles only and based only on the availability of electric charging facility only.

Finally, in [20], this work proposes each parking area to have its management system in addition to a separated management and reservation system, which would increase the overall system complexity. Also, the proposed solution is not a centralized reservation system as drivers are allowed to reserve directly from the parking areas. Therefore, the parking areas are not under the control of the reservation system. This work proposed and each car could be equipped by On Board Unit (OBU), which is considered overhead.

In conclusion, there is no complete system for parking based on the requirements of car drivers with benefits for both car drivers and parking lot owners. These systems don't encourage houses/buildings owners to share their private parking lots in the free times.

III. System Architecture

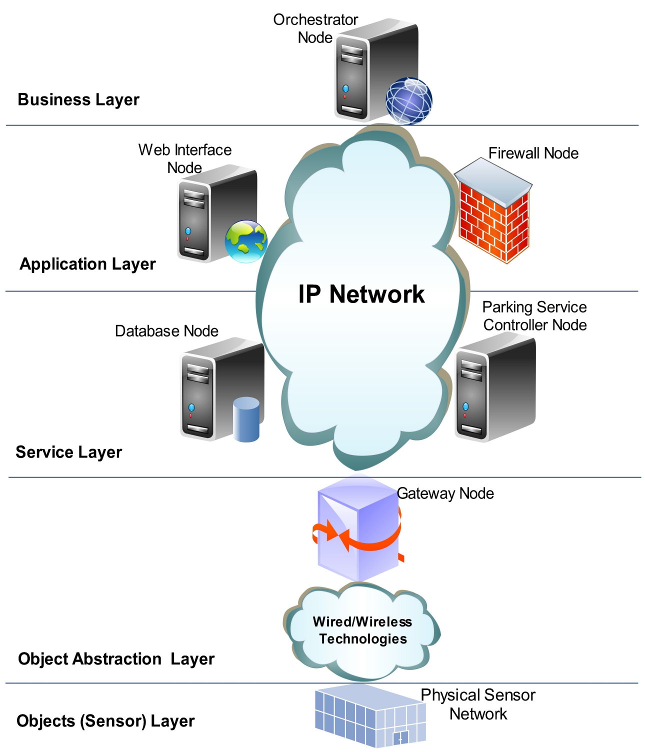

Fig. 1. Intelligent Parking System Architecture based IoT Five-Layers Model

The proposed parking architecture is based on the IoT five-layers model as it is the most applicable for applications based on IoT [3]. The proposed system components are distributed over the IoT layers and each one has a specific function(s) for an efficient business model as shown in Fig.1.

First, each server or function within the proposed model will be titled as a functional node and in the real implementation one server can peform two functions or more. Starting from top to bottom, layer five is the Business Layer (BL) which is considered as the orchestrator node of the work flow all over the system model. It is responsible for managing all the system model activities within the proposed service. Moreover, it is responsible for administering the service that will be implemented over the model's nodes. Therefore, it is obligated also to manage the validity of the model in terms of efficiency as well as the design semantics by monitoring and evaluating the function of each model node.

Layer four is the Application Layer (AL), which is concerned with two main issues. First, there is a web-interface node to facilitate the customers/drivers access to the parking system. Consequently, there is a need for a firewall to prevent unauthorized access, which makes it a secured component.

The Service Management Layer (SML), which stands for layer three is in between the AL and the Object Abstraction Layer (OAL). It consists of two nodes, the parking service controller node and the database (DB) node. The parking service algorithm is placed in the parking service controller node. This node is in charge of taking decisions based on the available information about the free parking lots that is recorded in the database node and the requests of customers coming from the web-interface node. The DB node is the local storage of the information collected from the parking areas about the status of the parking lots. DB node may also have information about the traffic status of the parking areas' vicinity and the normal distribution of customers parking requests based on the month/day/hour. This information would be useful for the server controller node when operating the smart parking system.

Layer two of the IoT model is the Object Abstraction Layer (OAL). Its responsibility is concentrated on collecting the status of parking spot and traffic congestion areas. This data is collected from the physical sensors and actuators of the object layer and sent to the database node in the SML. The main layer node is a Gateway node which works as a communication protocols translator. As the sensors communication protocols technologies are different, there is a need for the Gateway function to collect the information from each sensor based on its communication technology (WiFi, Zigbee, Bluetooth, RFID, Near Field communication, etc.) and send them by a unified communication protocol to the database node.

The Object Layer (OL) constitutes the physical or device layer. It consists of the physical sensors and actuators of the IoT world that provide the needed, which in our case the parking space status.

IV. Model In Action

A. Proposed Model Parameters

This novel model provides the customers who are relatively away from the event location with a parking spot in case they will park their cars for long periods of time and would like to be charged according to a minimum tariff plan. It also considers if customers arrive early and have time to walk from the parking area to the event location. Moreover, the tariff plan is expected to be high if customers prefer a parking lot close to the event location for any reason like having difficulty in walking, during rush hours, short term parking, late arrival, etc. All these factors will be considered when proposing the best parking lot and spot for the customer.

The proposed intelligent parking system uses some inputs provided by the customers to select the best parking spot. These Parameters influence the function of the proposed model and hence its utilization. These parameters should be taken into consideration when deciding the best parking lot and spot to be reserved, and they are listed as follows:

- Event location.
- The expected arrival time A_e; the parking lot will be reserved and paid for starting from time A_e.
- The reservation time S_e, which indicates when the customer reserves a parking lot.
- The expected Departure time D_e to calculate the parking period and hence calculate the expected parking cost. This parameter can be input by the customer or be automatically calculated by the system. It is to be noted that customers may be charged according to a different tariff plan after that time.
- T_e stands for the event duration.
- D_m the event location of the reservation occurred at the time of day m.
- E_e stands for the location of the event a customer is going to.
- For charging, customers have the ability to choose between two options; tariff limit or walking-distance limit. Based on the criteria of the customers, the system will select and recommend the best parking lot.
- H_e which is the day rush hours that affects the parking tariff at that event time.

B. Model Operational Algorithm

Figure 2 shows the flowchart of the reservation system algorithm. This algorithm can be divided into three distinct parts. Part one is dedicated to the driver parking lot reservation process. It starts with the driver request containing the driver first point, event location, and if he prefers lower tariff or shorter walking-distance. Based on that, the proposed system searches the availability at parking lot(s). In case there are available parking lots, the driver's request will proceed to part two of the system reservation and if not, the system will inform the driver.

In part two, the proposed system controller initiates the game competition between the available parking lots and ends by electing the best choice for the driver with its details (location, tariff, distance from the driver starting point). This part ends by a reservation confirmation from the driver based on the received election from the system controller, else, part one will be repeated again.

In part three, the proposed system controller starts activating the parking lot resource reservation in the system database and also charges the fees for the first hour.

A confusing scenario may happen, when two parking lots are at the same distance from the event but one of them is closer to the initial location of the driver and the other is away. According to the proposed system model, the controller output proposes the two parking lots of the same specifications (distance to the event, tariff) as both are game winners. According to the proposed algorithm, the driver will confirm choosing the best parking lot that suits him as shown in Fig.2, part 2, the second step. The system will not prefer the close parking lot as it may take more time to reach the closer parking lot due to traffic jams or planned/unplanned maintenance on the way to this parking lot or for any other reason, while the far than parking lot is more suitable in spite of its relative far distance.

C. Model Nodes Functional Workflow

Figure 3 shows the proposed parking system messages workflow. It starts when the web interface node receives a parking request (1) from a driver. This request contains the selected location, time of arrival, and according to that, the web interface node offers the parking conditions (2) to the driver. Based on the web interface node, the driver will confirm (3) the parking reservation condition which is based on two options; tariff limit or walking-distance limit. Hence, the web interface node will send the driver parking request (4) combined with his request condition to the parking service controller node. After that, the parking service controller node starts searching the database node (5-6) to get all the available parking lots that are compatible with the driver's requirements. Then, parking service controller starts the game competition between the search result

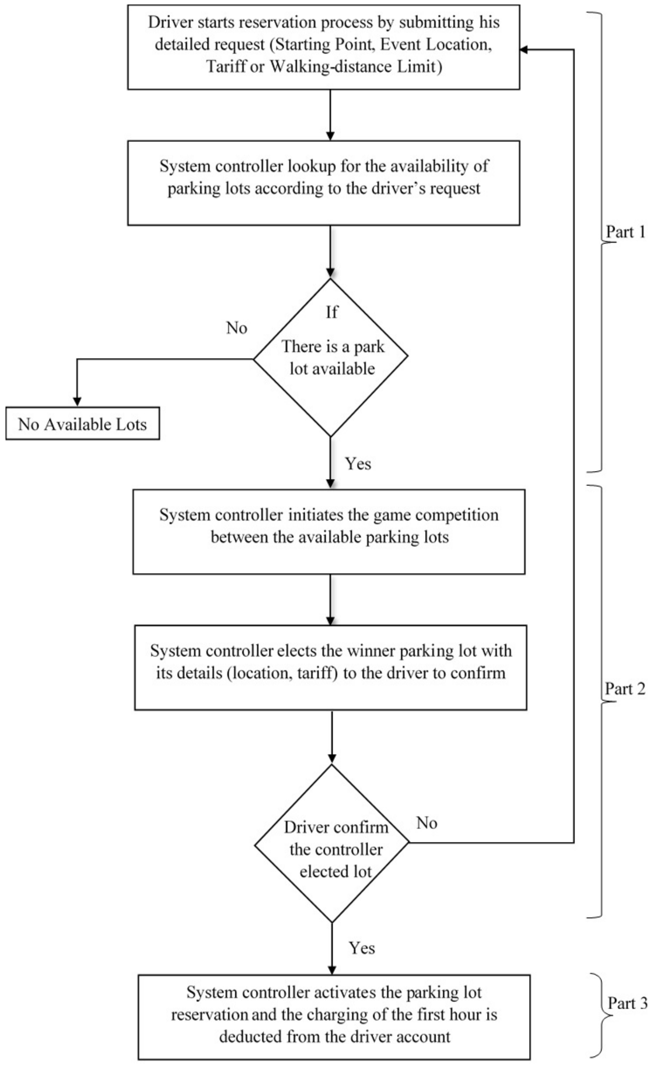

Fig. 2. Parking System Algorithm

parking lots (7) to inform the driver through the web interface node by the winner which stands for the best parking lot matching the driver's requirements (8-9). The work flow next steps are based on the driver confirmation. Once the driver confirms the parking lot reservation request (10-11), the parking service controller node takes four actions. First, the parking service controller node changes the parking lot status from free to reserved in the database (12). Second, it deducts the first hour charge from the driver account (13). Third, it changes the parking lot sensor LED indication from green to yellow that stands for reserved through the gateway node (14-15). Finally, it requests the reserved parking lot map location from the database node (16) and sends it to the driver to guide his reach to the parking lot (17-18).

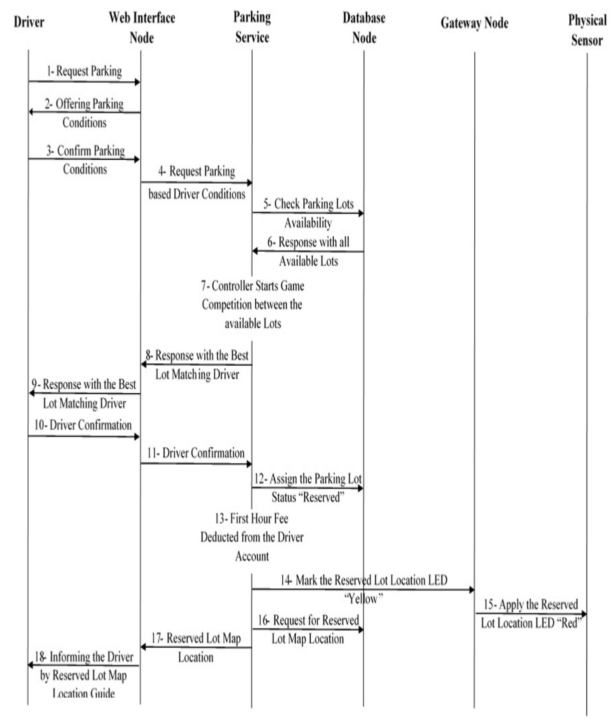

Fig. 3. Model Nodes Functional Messages Flow

V. Game Theory Model

The reservation assignment starts when the system controller receives a request for reserving a parking lot. The purpose of the game is to find and decide the best choice for reserving a parking lot. Each car driver searching for a parking lot must send a request considering the following parameters:

- How far the parking lot is acceptable to be from the event location.
- How much the driver is willing to pay per hour.

Consider there are n parking lots, where $n = 1, 2, 3.....N$. The game algorithm starts when a car driver tries to reserve a parking spot in a certain area. The car drivers have two choice modes; tariff limit or walking-distance limit as stated above. In the tariff limit mode, the car drivers are mostly interested in saving money and accept to park in lots that are relatively distant from the event location. Therefore, all the parking lots in the vicinity will go through the game competition. On the contrary, the walking-distance limit will not affect the game competition as the car drivers don't care to pay extra fees for parking in closer lots to the event location. Each parking lot competes in this game based on the customer's parameters which are S_e, A_e, and D_e.

Upon the car driver choice mode, the parking system controller starts the game competition with the available and eligible parking lots. The priority of each parking lot can be calculated based on its offer as follows:

$$Y_{m,n} = R_{m,n} - W_{m,n}E_{m,n} \tag{1}$$

where $R_{m,n}$ is the reservation task offer of each parking lot, m and n stand for the reservation time of day and the parking lot ID, respectively. The reservation time of day value varies from 1 to 1400 corresponding to the 24 hours. For simplicity, one reservation task per minute is assumed. $W_{m,n}$ stands for the weight of each parking lot based on the car driver choice whether tariff or walking-distance limit. $E_{m,n}$ is the penalty of walking that reflects how far the parking lot from the event location. The term $W_{m,n}E_{m,n}$ is considered a penalty, as it adds to the overhead of the parking lot offer according to the choice of the car driver. It is to be noted that the parking lot priority increases with the increase of $Y_{m,n}$.

For more clarity, if the car driver prefers not to walk and hence he is able to pay extra fees, so $W_{m,n} = 1$ and each parking lot overhead will correspond to its location with respect to the event location. The penalty $E_{m,n}$ has a fractional value changing from '0' for the parking lot at the same place of the event location to '1' for the farthest away parking lots. On the contrary, the weight of the penalty changes inversely if the car driver cares about how much he will have to pay. For this, $W_{m,n}$ value degrades by the percentage accepted by the car driver until reaching '0' if he does not mind walking for a long distance to reach the event location and the value of $E_{m,n}$ also changes from '0' to '1' based on its location compared to the event location.

Each parking area has a utility decision function that will be calculated in the service system controller. The utility function of each parking lot L can be expressed as follows:

$$U(R_{m,n}) = \psi(R_{m,n})(R_{m,n} - \frac{1}{I_{m,n}D_{m,n}}) \tag{2}$$

where $\psi(.)$ is the probability of the parking lot to win the game competition, $I_{m,n}$ is the discount factor which is used to encourage customers to park in areas away from traffic congestion areas such as city centers. Also, to perform a uniform distribution of the cars over the available parking areas which alleviates the congestion of certain areas, the discount factor depends on the mentioned customer's parameters and $D_{m,n}$ reflects the distance to walk to the event location.

$$I_{m,n} = T_e + G_e \tag{3}$$

where T_e is the expected parking duration and G_e is the difference period between the reservation and arrival times. The parking duration is calculated as the difference between the expected departure time D_e and arrival time A_e as shown in the following equation.

$$T_e = D_e - A_e \tag{4}$$

Also, G_e is calculated according to the following equation.

$$G_e = A_e - S_e \tag{5}$$

The walking distance between the event location and each parking location is calculated according to the following equation.

$$D_{m,n} = D_{p,n} - D_m \tag{6}$$

where $D_{p,n}$ and D_m are the parking location of lot n and the event location of the reservation occurred at the time of day m, respectively. The calculation of the probability of the parking lot to win the game competition is distributed based on the pdf $f(.)$ and cdf F(.), hence

$$\psi_n(R_{m,n}) = (1 - F(R_{m,n}))^{N-1} \tag{7}$$

Assuming $f(.)$ is an estimated distribution by the system controller of average μ and variance σ. These values can be calculated according to the prediction of system load interpreted from the dependency factors as will be explained in the following paragraph.

The probability of choosing to park a car in an area close to an event is expected to be decreased with the increase of the event duration T_e, distance between the park area and the location of the event $D_{m,n}$, and with the arrival time. On the contrary, it increases if the reservation occurred early before getting close to the event date. The following Table I defines the symbols used in the game theory model.

VI. Game Theory Model Solution

The System decision function to choose the best parking lot is based on two factors which are the tariff and walking distance from the parking area to the event location. A parking lot will win the challenge of the parking lots utilities based on a rational relation between the parking cost and walking distance. Therefore, the main goal of this game solution is to calculate the value of each parking lot $R_{m,n}$. The game competition can be modeled by Nash equilibrium approach [21] as it is a non-cooperative game, where each game object would like to optimize its utility function.

To solve this problem, it is required to reach the Nash Equilibrium Point (NEP) defined by $R^*_{m,n}$ in which each

TABLE I
GAME THEORY USED SYMBOL

Symbol	Definition
$R_{m,n}$	Reservation Task Offer
A_e	Arrival Time
S_e	Reservation Time
D_e	Departure Time
T_e	Parking Duration
G_e	Difference period between the reservation and arrival times
m	Reservation time of day
n	Parking lot ID
$D_{m,n}$	Walking Distance
$D_{p,n}$	Parking Location of lot n
$I_{m,n}$	Discount Factor
$W_{m,n}$	Each parking lot weight
$E_{m,n}$	How far the parking lot
ψ	Probability of the parking lot to win the game competition

object has no incentive to deviate unilaterally from the NEP (17) and considering there are L parking lots each of which has its winning probability ψ. To reach the NEP, $R^*_{m,n}$ is given by:

$$F(R^*_{m,n}) = 1 + C_0(R^*_{m,n} - \frac{1}{I_{m,n}D_{m,n}})^{-1/(N-1)} \quad (8)$$

where $C_0 \in R$. For the system controller decision, it is obligated to look back to the probability to win a game. Therefore, by considering $Y_{m,i}$ and $Y_{m,j}$ are two random variables with the same given $f(.)$. Hence, each parking lot in order to win the game and take the reservation task should propose its offer as follows:

$$R_{m,n} = W_{m,n}E_{m,n} + max\{Y_{m,1}, Y_{m,2}, ..., Y_{m,N}\} \quad (9)$$

For identical independent distribution, we get:

$$\begin{aligned}\psi(R_{m,n}) &= P(R_{m,1} - W_{m,1}E_{m,1} > R_{m,n} - W_{m,n}E_{m,n}) \\ &\times ... \times P(R_{m,N} - W_{m,N}E_{m,N} > R_{m,n} - W_{m,n}E_{m,n}) \\ &\times P(R_{m,N} > R_{m,n}) \quad (10)\end{aligned}$$

$$\begin{aligned}\psi(R_{m,n}) &= (1 - P(R_{m,1} - W_{m,1}E_{m,1} \\ &\leq R_{m,n} - W_{m,n}E_{m,n})) \times ... \times \\ &(1 - P(R_{m,N} - W_{m,N}E_{m,N} \leq R_{m,n} - W_{m,n}E_{m,n})) \quad (11)\end{aligned}$$

Hence, obtain the following:

$$\psi(R_{m,n}) = (1 - F(R_{m,n} - W_{m,n}E_{m,n}))^{N-1} \quad (12)$$

where $F(R_{m,n} - W_{m,n}E_{m,n}) = P(Y_{m,j} \leq Y_{m,n})$ is the cdf of the random variable $Y_{m,n}$.

To win the game, the parking lot should send its offer based on $R^*_{m,n}$ and $Y_L(R_{m,n})$. An explicit formula of the utility function of each parking lot (7) can be given as follows:

$$\begin{aligned}U(R_{m,n}) &= [(1 - F(R_{m,n} - W_{m,n}E_{m,n}))^{N-1}] \\ &\times [R_{m,n} - \frac{1}{I_{m,n}D_{m,n}}] \quad (13)\end{aligned}$$

The Derivation of the utility function given by (13) result the NEP of the game using:

$$\frac{\partial U(R_{m,n})}{\partial R_{m,n}} = 0 \quad (14)$$

which is equivalent to:

$$\begin{aligned}&[1 - F(R_{m,n} - W_{m,n}E_{m,n})^{N-2}](1 - N) \\ &\times F'(R_{m,n} - W_{m,n}E_{m,n}) \times (R_{m,n} - \frac{1}{I_{m,n}D_{m,n}}) \\ &+ [1 - F(R_{m,n} - W_{m,n}E_{m,n})^{N-1}] = 0 \quad (15)\end{aligned}$$

Equation (15) can be simplified as follows:

$$\begin{aligned}&(1 - F(R_{m,n} - W_{m,n}E_{m,n}))^{N-2} \times [(1 - N) \\ &F'(R_{m,n} - W_{m,n}E_{m,n}) \times (R_{m,n} - \frac{1}{I_{m,n}D_{m,n}}) \\ &+ (1 - F(R_{m,n} - W_{m,n}E_{m,n}))] = 0 \quad (16)\end{aligned}$$

This yields two possibilities as follows:

- $F(R_{m,n} - W_{m,n}E_{m,n}) = 1$ or,
- $(N-1)F'(R_{m,n} - W_{m,n}E_{m,n}) + F(R_{m,n} - W_{m,n}E_{m,n}) = 1$

Solving the second possibility which is more general since it includes the first possibility as well. Also, considering the density of $Y_{m,n}$ is exponential of parameter λ. So, $Y_{m,n} \sim e^{\lambda}$

$$F(R_{m,n} - W_{m,n}E_{m,n}) = 1 - e^{-\lambda(R_{m,n} - W_{m,n}E_{m,n})} \quad (17)$$

Using (15) and (17) to calculate the NEP:

$$\begin{aligned}&(1 - N)\frac{\partial(1 - e^{-\lambda(R_{m,n} - W_{m,n}E_{m,n})})}{\partial R_{m,n}}(R_{m,n} - \frac{1}{I_{m,n}D_{m,n}}) \\ &+ (1 - (1 - e^{-\lambda(R_{m,n} - W_{m,n}E_{m,n})})) = 0 \quad (18)\end{aligned}$$

and Finally:

$$\begin{aligned}&(1 - N)(\lambda e^{-\lambda(R_{m,n} - W_{m,n}E_{m,n})})(R_{m,n} - \frac{1}{I_{m,n}D_{m,n}}) \\ &+ e^{-\lambda(R_{m,n} - W_{m,n}E_{m,n})} = 0 \quad (19)\end{aligned}$$

which can be expressed in more detail as follows:

$$(1-N)(\lambda e^{-\lambda(R_{m,n}-W_{m,n}E_{m,n})})(R_{m,n}- \frac{1}{(T_e+G_e)(D_{p,n}-D_m)}) + e^{-\lambda(R_{m,n}-W_{m,n}E_{m,n})} = 0 \quad (20)$$

VII. PERFORMANCE VALIDATION

This section investigates the performance of the developed mathematical model. Evaluation has been carried out using Matlab [22]. The simulation model is built based on different parameters listed in Table II. Five simulation scenarios are used to test the validity of the proposed mathematical model by measuring the effect of different parameters separately. The unit of the parking lots offers is normalized to the value 1.

The five scenarios simulate and differentiate between this proposed work model and the model of [20], An Agent-Oriented Smart Parking Recommendation System for Smart Cities (ASPIRE). Simulation scenarios study the result of the proposed model and ASPIRE model. These parameters are the effect of each of parking duration, parking lot location and finally the parking lot reservation time.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
n	5 Parking Lots of IDs = 1, 2, 3, 4, and 5
D_m	0 Meters
$D_{p,n}$	100 to 500 Meters
A_e	12pm
D_e	13pm to 18pm
S_e	1 to 12 Hours

In scenario one, the affect of the parking duration on the parking lots offers is studied. Figure 4 shows the effect of increasing the parking duration calculated in (4). Parking duration varies from one to five hours. All the simulation parameters are fixed except the departure time D_e. Parking lot 1 location is supposed to be the nearest one, while parking lot 5 is the farthest one. As shown in the figure, each parking lot offer decreases with the increase of the parking duration as the revenue increases due to the long parking.

According to the ASPIRE model, parking duration has no effect on the parking lot offer. However, Fig. 4 shows the results of the ASPIRE model which are the default performance and even when considering ASPIRE performance is affected by the parking duration parameter which is presented as ASPIRE (Average). To compare with the ASPIRE model, it is considered that it is affected by the parking duration parameters and its performance is assumed to have an average of the parking lots offers. When comparing the two models, as clear in the figure, the performance of the game model is better than the ASPIRE model based on its default and average results.

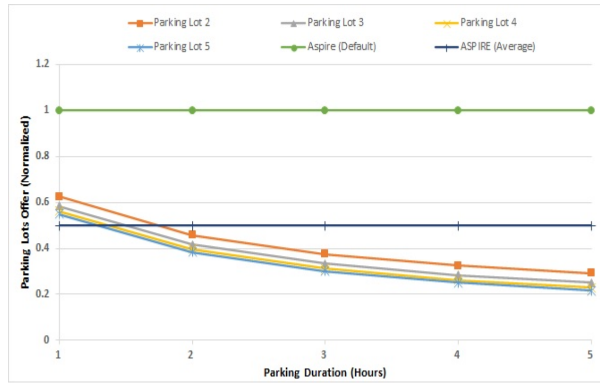

Fig. 4. Parking Duration Effect

In scenario two, the effect of the parking lots locations on the offers is studied. Two factors affecting the choice of the best parking lot: price and proximity to the customers' destinations. Therefore, far away parking lots rely on decreasing their offers to attract a category of customers who care more about the parking fare specially in case of long parking periods. All the simulation parameters are fixed in this scenario and the parking lots offers are studied with respect to the locations. The locations of the parking lots vary from the nearest to the farthest one with respect to the event location. Figure 5 shows the simulation results. As shown in the figure, the parking lots decrease their offers. This is to compensate how far their locations to the customers' destinations. As obvious in the figure, the parking lots offers reduction is not linear. This is because the calculation is exponentially based as shown in (20).

As shown in the Fig. 5, the ASPIRE model achieves the same performance as the game model. This is due to using the same rate of the parking lots offers for both models. For clarity, the difference here is that the proposed algorithm is based on nominating the best parking lot to the driver based on his requirements that's is not provided by ASPIRE algorithm. Hence, this paper model achieved better performance over the ASPIRE model.

Scenario three studies the affect of the early driver's reservation request on the parking lots offer. Figure 6 shows the effect of the parking slot reservation time relative to the arrival time. The x-axis refers to the duration between

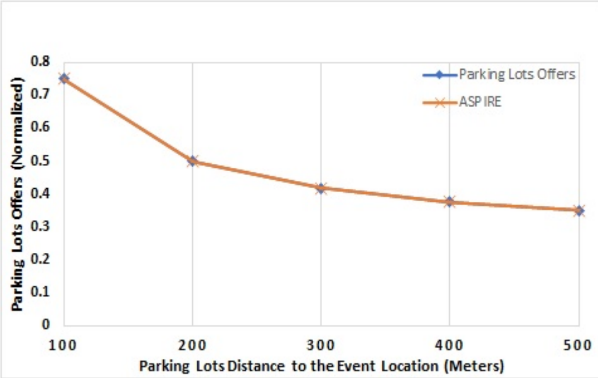

Fig. 5. Parking Lots Location Effect

the reservation and arrival times in hours. As shown in the figure, parking lots offer increase as the customer reserves directly before his arrival. This result is compatible with the marketing rules that the customer gets the benefit of a low service price when he reserves it early.

According to the ASPIRE model, its default performance is not affected by the early drivers reservation request before his arrival. Therefore, in this scenario the average value of the parking lot offer is considered to be the ASPIRE model result to compare with. As shown in Fig. 6, the performance of the game model is much better within an early reservation period of twelve hours to two hours before arrival. Starting from one-hour reservation period before the drivers arrival, the performance of the ASPIRE model overcomes the paper model due to considering the average value of the parking lots offers.

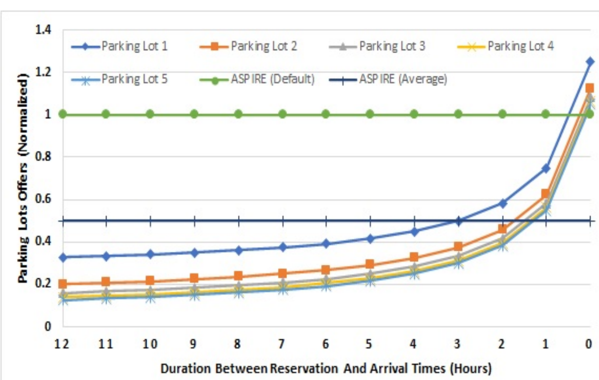

Fig. 6. Reservation Time Effect

Scenario four concludes the total cost paid for car parking of a duration 1, 2 and 3 hours. A real parking fee in France [23] is used in this simulation. The highest parking fee mentioned in [23] is assumed to be for parking lot 1, which is considered the closest parking lot to the driver destination. ASPIRE model is caring of the walking time of the car driver's, therefore, for generality its parking rate fee is considered to be average. The performance of both models are shown in Fig. 7. As obvious, this proposed model achieves better performance depending on providing many cars park lots choices of different fee rate to fit the drivers. In addition to that, the proposed solution performance will be superior in case of ASPIRE model preferred to reserve the closest parking lot as it is interested of decreasing the walking time.

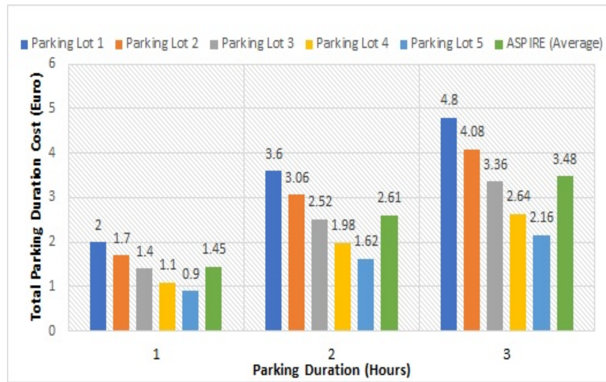

Fig. 7. Total Parking Cost

In scenario five, the effect of each model decision is studied with respect to the driver's walking distance. As shown in Fig. 8, ASPIRE model gets the best decision to provide the lowest driver's walking distance to his destination. The same results is achieved by the proposed model by choosing park lot 1, but the driver's walking distance increases with the choice of other parking lots 2 to 5. This is true from the first sight, but there is an important parameter didn't taken into consideration while taking the decision which is the parking fee. This is important especially when the driver cares of how much will he pays, therefore, ASPIRE model result may not suit the driver. Hence, by taking into consideration the driver's suitable walking distance and the cost get to the best decision as the proposed model does.

VIII. CONCLUSIONS

In this paper, a solution for a collaborative-aware intelligent parking system based on IoT is proposed. Game theory is used also for modeling the reservation system of the proposed solution which provided a high performance according to the simulation results.

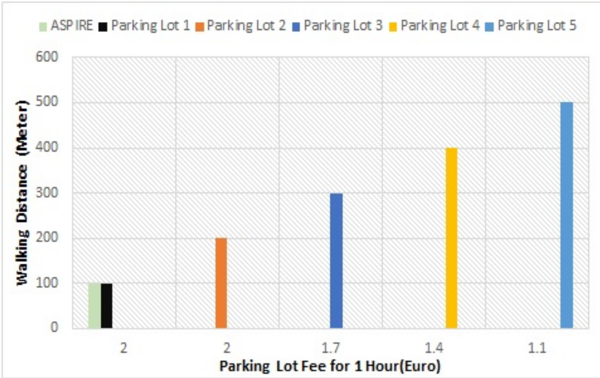

Fig. 8. Driver's Walking Distance

Two studies [1-2] are reviewed mentioning the dangerous effects on the world especially in big cities due to the tons of CO_2 emissions resulting from the wasted fuel drivers use for finding a park. Regarding our model we succeeded to propose a solution to get rid of the parking problems by eliminating the number of cars circulating in certain areas to find a suitable park, hence saving fuel burned by car motors. Consequently, that will have a great impact on the environment and will provide the green environment that the world is looking for and this is one of the main contributions of the paper.

The importance of this work stems from many factors. First, this solution simplifies and streamlines finding a parking space and consequently the traffic jam. In most cases, car drivers are forced to park in expensive parking lots and/or parking in distant parking lots which requires them to walk long distances to reach their distentions as these parking lots are the only ones available. In addition to that, the proposed solution answers the main question of the car drivers; the locations of free parking lots. Therefore, this model is expected to prevent cruising in order to find free parking lots. Second, the model encourages individuals and the owners of private corporations to get the financial benefit by joining the system and share their free parking lots wholly or partially whenever available. Third, this proposed model provides a green environment which is a main global objective. Moreover, this model is a promising collaborative platform for building on much more added value fitting the future technology users.

Simulation results of the proposed game model are evaluated through different scenarios. These scenarios are based on testing the main factors influencing the parking lots offers and hence the competition between them. The proposed game model achieves high performance with respect the following influencing parameters; parking duration, duration between drivers reservation request and his arrival time and finally the parking lots location.

The performance results of the proposed game model are compared with ASPIRE model. The proposed model achieved better performance along the simulation scenarios. These results proved the validity effectiveness and high performance of this approach.

For future work, the new challenge is to build a test-bed to make a practical assessment and for better resolution.

REFERENCES

[1] http://www.telegraph.co.uk/news/2017/02/01/motorists-spend-four-days-year-looking-parking-space/, Last seen date: 1-2020

[2] D. Shoup, "Cruising for Parking", Access Magazine, no. 30, spring 2007.

[3] Y. Zheng, S. Rajasegarar, C. Leckie, and M. Palaniswami, "Smart Car Parking: Temporal Clustering and Anomaly Detection in Urban Car Parking", IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP) Symposium on Information Processing, Singapore, 2014.

[4] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, Senior Member, IEEE"Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications", IEEE Communication Surveys & Tutorials, vol. 17, no. 4, fourth quarter, pp. 2347-2376, 2015.

[5] Y. Geng and C. G. Cassandras, "A New Smart Parking System Based on Optimal Resource Allocation and Reservations", 14th International IEEE Conference on Intelligent Transportation Systems, Washington, DC, USA, 2011.

[6] J. Yang, J. Portilla and T. Riesgo, "Smart Parking Service based on Wireless Sensor Networks", 38th Annual Conference on IEEE Industrial Electronics Society (IECON), Montreal, QC, Canada, 2012.

[7] R. Elisa Barone, T. Giuffr, S. M. Siniscalchi, M. A. Morgano, G. Tesoriere, "Architecture for parking management in smart cities", IET Intelligent Transport Systems, vol. 8, no. 5, pp. 445-452, 2014.

[8] X. Zhao, K. Zhao, and F. Hai, "An Algorithm of Parking Planning for Smart Parking System", 11th World Congress on Intelligent Control and Automation Shenyang, China, 2014.

[9] Z. Ji, I. Ganchev, M. ODroma, L. Zhao, and X. Zhang, "A Cloud-Based Car Parking Middleware for IoT-Based Smart Cities: Design and Implementation", Sensors Journal, 2014.

[10] T. N. PHAM, M. TSAI, D. B. NGUYEN, C. DOW, and D. DENG, "A Cloud-Based Smart-Parking System Based on Internet-of-Things Technologies", Special Section in IEEE Access: Emerging Cloud-Based Wireless Communications and Networks, vol. 3, pp. 1581-1591, 2015.

[11] Y. Atif, J. Dinga, and M. A. Jeusfelda, "Internet of Things Approach to Cloud-Based Smart Car Parking", The 7th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN), vol. 98, pp. 193198, 2016.

[12] M. Fraifer and M. Fernstrm, "Designing an IoT Smart Parking Prototype System", Thirty Seventh International Conference on Information Systems (ICIS), Dublin, Ireland, 2016.

[13] R. Mangiaracina, A. Perego, A. Tumino, G. Miragliotta, G. Salvadori, "Smart Parking management in a Smart City: costs and benefits", IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), Bari, Italy, pp. 27-32, 2017.

[14] N. Pham, M. Hassan, H. Nguyen, D. Kim, "GS1 Global Smart Parking System: One Architecture to Unify Them All", IEEE International Conference on Services Computing (SCC), Honolulu, HI, USA , pp. 479-482, 2017.

[15] M. Al-Jabi, H. Sammaneh, ”Toward Mobile AR-Based Interactive Smart Parking System”, IEEE 16th International Conference on Smart City, Exeter, United Kingdom, pp. 1243-1247, 2018.
[16] M. A. Kuhail, M. Boorlu, N. Padarthi and C. Rottinghaus, ”Parking Availability Forecasting Model”, IEEE International Smart Cities Conference (ISC2), Casablanca, Morocco, 2019.
[17] S. Gren, D. F. ncevarlk, K. D. Yldz and T. Z. Hakyemez, ”On-Street Parking Spot Detection for Smart Cities”, IEEE International Smart Cities Conference (ISC2), Casablanca, Morocco, 2019.
[18] C. Ajchariyavanich, T. Limpisthira, N. Chanjarasvichai, T. Jareonwatanan, W. Phongphanpanya, S. Wareechuensuk, S. Srichareonkul, S. Tachatanitanont, C. Ratanamahatana, N. Prompoon and M. Pipattanasomporn, ”Park King: An IoT-based Smart Parking System”, IEEE International Smart Cities Conference (ISC2), Casablanca, Morocco, 2019.
[19] Y. Guan, W. Feng, E. J. Palacios-Garcia, J. C. Vsquez and J. M. Guerrero, ”VICINITY Platform-based Load Scheduling Method by Considering Smart Parking and Smart Appliance”, 15th International Conference on Distributed Computing in Sensor Systems (DCOSS), Santorini Island, Greece, 2019.
[20] S. R. Rizvi, S. Zehra, S. Olariu, ”ASPIRE: An Agent-Oriented Smart Parking Recommendation System for Smart Cities”, IEEE Intelligent Transportation Systems Magazine , vol. 11, no. 4, pp. 48-61, 2019.
[21] D. Fudenberg, J. Tirole, ”Game Theory”, 1991.
[22] Matlab, URL https://www.mathworks.com/products/matlab.html
[23] https://www.justlanded.com/english/France/Articles/Travel-Leisure/Parking, Last seen date: 11-2020