Dynamic Parking Guidance Architecture Using Ant Colony Optimization and Multi-agent Systems

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***Abstract*—Nowadays, drivers have great difficulty finding a parking space easily due to the traffic congestion in some areas and the distribution of car parks within the city. This work aims to design a new system that will allow a vehicle driver to find the best route between his real-time position and parking with available places in a specific area. Our system is based on a distributed swarm intelligence strategy using the ant colony algorithm, cloud system, and multi-agent systems to offer an optimal solution toward the nearest car park in the city. Our solution will improve the use of available parking in the city.**

***Index Terms*—Ant Colony Optimization (ACO), cloud system, multi-agent systems, traffic road**

I. Introduction

Providing high-quality service in networks raises many difficult challenges. One of them is to determine an optimal path that takes into account a set of constraints while maintaining the use of network resources. This implies the need to impose an additional optimality requirement on the feasibility problem.

we can use a cost function that the selected achievable path is optimal. In general, the selection of a multiple constraint path is an NP-complete problem. Heuristic and approximation algorithms with polynomial and pseudo-polynomial time complexities are often used to deal with this problem. However, existing solutions are limited in terms of over-computing that cannot be used for the operation of online networks, i.e., low performance. Moreover, they only deal with special cases of the problem (e.g., two constraints without optimization, one constraint with optimization, etc.).

For the problem of multi-constrained feasibility, some scientists have proposed a non-linear cost function. In this paper, we propose an efficient heuristic algorithm for the parking guidance problem in smart cities.

In this work, we present an improved version of the algorithm that was proposed by the authors in [1]. The algorithm that was proposed allows the driver to find the optimal path between his position and a parking space in a closed car park taking into account the constraints of the network. But this algorithm shows an inconvenience because it does not consider the final destination of the driver.

Here we will propose a distributed algorithm to solve the parking problem and which will allow the user to find the optimal path between his position and an indoor car park in a chosen area. This path must be optimal in terms of (distance, traffic, time).

The proposed architecture is based on a set of intelligent elements that will collaborate together to find the best solution for drivers.

The new strategy is based on multi-objective Ant Colony Optimization (ACO), cloud system and multi-agent systems. The method aims to manage the parking routing problem in real time using the information stored in the cloud. This information is collected from different intelligent sources such as (parking sensors, service station agents, road traffic sensors ...).

The proposed algorithm is based on Ant Colony Optimization (ACO) [2] which is a very powerful method for combinatorial optimization problems, Vehicle Routing problems [3], [4]. The ant colony optimization algorithm is based on the behavior of ants, which aims to find the shortest paths between the colony and the food source. Ants work to find the optimal path in an organized and distributed way. The most important ingredient of ACO is pheromone, which is a chemical substance deposited by ants and its concentration forms the trajectory map. Paths containing the highest concentration of pheromones represent the best trajectories. The outline of this paper is as follows.

In the next part, we summarize researches developed with the aim to solve the guidance parking problem. In Section 3, we describe the physical decentralized architecture for managing multi constraint parking problems in smart cities. The ant colony optimization algorithm is defined in Section 4. Section 5 explains the mathematical model to solve the parking routing problem based on ACO Algorithm. Section 6 gives an overview of the system architecture. The perspectives and conclusion are given in the last two sections.

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II. PREVIOUS WORKS

Authors in [5] introduce the concept of collaborative path-finding to the parking problem to alleviate traffic congestion on routes toward parking areas. The proposed algorithm selects a collective route that minimizes the total congestion by applying A-star to the collective routes. When congestion is detected within a route, the algorithm redirects random portions of the traffic to create a new route which is reintroduced back into the algorithm.

This paper [6] proposed a parking guidance system based on wireless sensor network and Dijkstra optimization algorithm. The system is composed of three elements: parking lot sensors, sink node and parking manager which will allow us to find the optimal route toward a parking place.

Authors in [7] introduce parking guidance and information system based on wireless sensor system. The two guidance systems use a sensor network to capture real-time information about all parking and send it to the sink node which will transmit it to the parking manager. At the end, the system will display the information and position of the parking spaces.

Other researches [8] propose a dynamic parking guidance system that combines parking destination switching and real-time traffic routing. Drivers can switch their parking destinations and routes during their trip to minimize their expected travel costs.

Choe designed a parking guidance system to manage parking area, collect the data through the computer controlling. The information of the parking lot and the road condition are displayed on the electronic road signs, and the rest of the parking space in the parking lot is updated in real time. The driver chooses the parking lot based on the indicator [9].

Song [10] proposed an intelligent parking lot navigation scheme based on the ZigBee technology of the Internet of things (IoT). It uses ZigBee and ultrasonic sensors to deal with the vehicle location, and improves the parking efficiency by modifying the shortest path algorithm.

Shin and Jun [11] proposed a guidance algorithm that takes into account dynamic parking conditions in the city. The test results were provided to validate the proposed algorithm.

Zheng *et al.* [12] have developed a prediction parking system using machine learning algorithms and real time data acquired from two big cities.

An intelligent parking approach based on meta-heuristic is proposed in [13] to find an optimal road toward a parking location.

In this paper [14], the authors propose a new guidance monitoring system that aims to detect vacant parking spaces and to propose the destination to the driver. When the driver reaches the car park, the system makes an update by informing the other car parks of the status of the new available parking space.

Other solutions have been made to solve the road traffic problems by using the cloud computing and the big data technologies to manage the traffic routing system, find optimal paths for drivers and guiding them toward a parking with available places. the authors [15] propose a novel strategy for routing vehicles to reach parking places in the minimum time.

The proposed system provides an intelligent guidance system to help drivers in the cities and avoid routes with a higher level of traffic congestion.

A parking routing system has been developed based on Genetic Algorithm (GA) to solve the problem of parking in big cities. In this work [16] authors propose an intelligent solution to find best places a parking lot. With this strategy, they can route inside the parking to reach the best vacant place in the minimum time.

This paper [17] proposes a new model of an intelligent adaptive traffic system linked to a set of things using the Internet that allows them to retrieve information in real time. The data collected by the different components are controlled and analyzed. The obtained data will be used to evaluate the state of the road network in a specific area. In addition, this system is able to help drivers by giving them real-time information about the traffic flow in that area.

In the present paper we are designing a decentralized parking routing solution to help drivers find the optimal route between their position in real time and an indoor car park with available places in a chosen area. Our solution must be optimal in term of (distance, traffic, time). The proposed system architecture is based on multi objective ACO, cloud system and multi agent systems.

III. DECENTRALIZED ARCHITECTURE FOR MANAGING MULTI CONSTRAINT PARKING PROBLEM IN SMART CITIES

The architecture (Fig. 1) is composed of a set of elements that are linked by a cloud platform. These elements are equipped with intelligent technologies that enable the collection and transmission of data to the cloud in order to be processed.

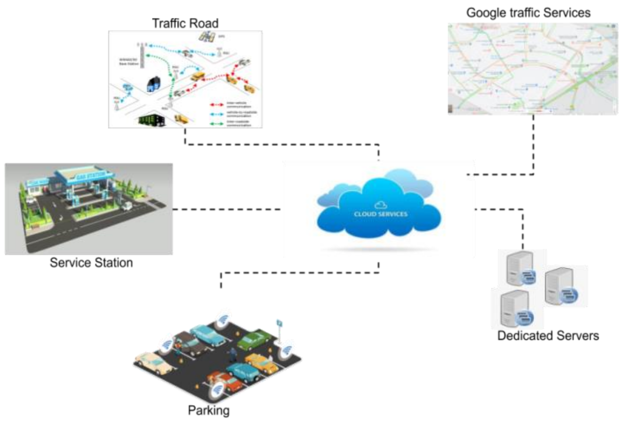

Figure 1. Physical system architecture for parking problem in smart cities.

Therefore, car parks must be equipped with intelligent sensors that will give an overview over the number of available spaces and the state of the car park. To get the traffic situation in real time, each road requires a certain number of road sensors.

Information's about each service station will be transmitted to the cloud through a specific agent.

Based on all these data, the system must be able to provide the optimal path to the driver, taking into account the distance and the traffic.

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A. Description of Physical Infrastructure

To better carry out the different services requested by the driver, a set of sensors must be deployed in each indoor parking to provide a continuous measure of parking status and number of vacant places. Data collected from various sensors is sent to a specific agent who will transmit this data to the cloud system through MQTT protocol. MQTT [18] (Message Queue Telemetry Transport) Protocol is a publish-subscribe based "light weight" messaging protocol that is used on top of the TCP/IP protocol.

B. Description of the Parking Routing System

The cloud provides data storage and computing resources for the parking routing system. When the cloud receives the request from the driver the system will catch the Coordinates of his real time position. To retrieve the traffic flow in a specific area we use road-side units (RSUs). The RSU receives information from its neighboring RSUs and computes the traffic at each junction based on its own traffic count and also on the number of expected vehicles approaching from the neighboring junctions. By controlling the transmission distance of each cell RSU's can obtain approaching traffic information in advance. Also we will use the Google traffic services. When all information is prepared, we will call our distributed algorithm to find the optimal path between the real time position of the driver and an indoor parking with available places. Our solution must fit the preferences of the driver in terms of distance, traffic and time.

IV. Ant Colony Optimization Algorithm

The ant Colony Optimization Algorithm (ACO) is a probability-based technique for resolving computational issues that can be limited to determining the best paths through graphs. Ant colony algorithms are one of the most successful examples of swarm intelligent systems, and have been applied to many problems like the classical traveling salesman problem, routing in telecommunication networks.

In fact, Ants while going from the nest to the food source deposit a chemical substance called pheromone. When they arrive at a decision point, like the intersection between roads, they make a probabilistic choice based on the amount of pheromone on the two roads.

At the beginning there is no pheromone on the two roads and therefore ants going from the nest to the food source will choose one of the two roads with equal probability. The ants choosing the shortest road will be the first to reach the food source. When it returns to their nest they will be attracted by the pheromone trail on the shorter path, however the shortest path will be chosen with higher probability than the longer one. New pheromone will be released on the chosen path, making it more attractive for other ants. While time passes, pheromone on the optimal route is deposited at a higher rate making the shorter path more selected until the end of iteration.

The chosen method is part of the heuristic algorithms that rely on distributed optimization concept and the amount of pheromones to solve combinatorial optimization problems [19]. The ACO algorithm is divided into three parts:

- Ants' trajectories will be constructed based on the computation of a probabilistic transition that is related to the amount of pheromones in each route. When the trajectories are built, the ants will update the amount of pheromones on each arc visited.
- The system will select routes that contain a higher level of pheromones in order to choose the most optimal solution.
- At the end of the process, the ants update the amount of the global pheromone on the paths that have been chosen by the system.

V. The Multi Constraint Parking System Using ACO Algorithm

In the present study, we suggest a mathematical model to improve the time needed to find an indoor car park by considering a set of constraints (distance, traffic, fuel quantity in the car, available spaces in each car park).

The ACO algorithm for parking problems is based on a set of ants working together simultaneously to find the right solution. Each ant will build a complete trajectory based on a given map.

The construction of the trajectory is described as follows: at the beginning, the ants start from the driver's location and select the next node to visit according to a probabilistic transition to calculate. The ant has two possibilities:

If the amount of fuel in the car is insufficient to reach a car park, the ants must select a service station to visit from the list of available service station locations.

The second choice consists in selecting a car park to visit from the list of available car parks. The procedure of searching for an optimal path starts again when the ants reach the car park position.

The optimal solution is defined based on the quantity of pheromone. In the proposed strategy the number of vehicles between two connected road sensors is related to the quantity of pheromone. Thus, when the number of vehicles is sent to the cloud, we use it to estimate the traffic flow between intersections and we consider the number of stationary vehicles as the inverse of pheromone amount. The main goal of our algorithm is to find best routes with less traffic flow and short distance .so ants will follow the routes with less traffic flow which mean higher amount of pheromone.

The problem will be modeled as a road network with distributed nodes. In our case , nodes present drivers, service stations, car parks and areas where D= {D_1, D_2,……., D_m} is the set of drivers searching for an indoor parking with available places in a specific area, P = {P_1, P_2,……., P_n} is the set of indoor parkings, S = {S_1, S_2, …, S_p} the set of service stations and A={A_1, A_2, …, A_r}is the set of areas.

Let G be the graph (Fig. 1) with vertices in (D ∪ P ∪ S) and the edges in E shall be determined as follows:

$$E = \{D_iS_j/1\leq i\leq m \text{ and } 1\leq j\leq p\} \cup \{S_iP_j/1\leq i\leq p \text{ and } 1\leq j\leq n\} \cup \{D_iP_j/1\leq i\leq m \text{ and } 1\leq j\leq n\}$$

We denote DiSj the distance between the vertice Di and Sj and tr(Di, Sj) the traffic flow between the vertice Di and Sj (between the driver Di and the service station (Sj) , SiPj the distance between the vertice Si and Pj and tr(Si, Pj) the traffic flow between (between the service station Si and the parking Pj) and DiPj the distance between the vertice Di and Pj and tr(Di, Pj) (between the driver Di and the parking Pj).

Each indoor parking belongs to a particular area as follows:

$$\exists P_i \in P, \exists A_j \in A / P_i \in A_j \; 1 \leq i \leq n \; and \; 1 \leq j \leq r$$

The purpose of the problem is to determine the optimal route for each driver looking for a parking space in a specific area, taking into account certain constraints. In this version of ACO for parking problems, each ant must create a route that allows the driver to reach a parking lot in the chosen area taking into account the constraints defined at the beginning of the paper. Each ant chooses the next node [20] to visit based on the value of the probabilistic transition. If the ant is in the driver's position, we have three cases (1), (2), (3):

$$p^k(D_i, S_j) = \frac{\tau^{\alpha}(D_i,S_j)\,\eta^{\alpha_1}(D_i,S_j)}{\sum_{\beta\in[\![1,p]\!]}\tau^{\alpha}(D_i,S_\beta)\,\eta^{\alpha_1}(D_i,S_\beta)} \quad (1)$$

where $\eta(D_i,S_j) = \frac{1}{D_iS_j}$ and $\tau^{\alpha}(D_i,S_j) = \frac{1}{tr(D_i,S_j)}$

At the beginning, the driver should specify the destination area. Before calculating the probabilistic transition, it is necessary to test whether the car park belongs to this area or not. We suppose that the area chosen by the driver is A_f with 1<f<r.

if ($P_i \in A_f$) Then

$$p^k(D_i, P_j) = \frac{\tau^{\alpha}(D_i,P_j)\eta^{\alpha_1}(D_i,P_j}{\sum_{\beta\in[\![1,n]\!]}\tau^{\alpha}(D_i,P_\beta)\eta^{\alpha_1}(D_i,P_\beta)} \quad (2)$$

Else

$$p^k(D_i, P_j) = 0$$

where $\eta\ (D_i,P_j) = \frac{1}{D_iP_j}$ and $\tau^{\alpha}(D_i,P_j) = \frac{1}{tr(D_i,P_j)}$

$\tau^{\alpha}(D_i,S_j)$: value of pheromone amount on route from D_i to S_j.

$\tau^{\alpha}(D_i,P_j)$: value of pheromone trail on edge from D_i to P_j.

$\eta(D_i,S_j)$: value of distance cost function from D_i to S_j.

$\eta\ (D_i,P_j)$: value of distance cost function from D_i to P_j.

Once the ant reaches the position of a service station, we use the value of the probabilistic transition to determine the next parking node to visit:

if ($P_i \in A_f$) Then

$$p^k(S_i, P_j) = \frac{\tau^{\alpha}(S_i,P_j)\eta^{\alpha_1}(S_i,P_j)}{\sum_{\beta\in[\![1,n]\!]}\tau^{\alpha}(S_i,P_\beta)\eta^{\alpha_1}(S_i,P_\beta)} \quad (3)$$

Else

$$p^k(S_i, P_j) = 0$$

where $\eta\ (S_i,P_j) = \frac{1}{S_iP_j}$ and $\tau^{\alpha}(S_i,P_j) = \frac{1}{tr(S_i,P_j)}$

$\tau^{\alpha}(S_i,P_j)$: value of pheromone trail which represents the inverse of number of stopping cars on edge from S_i to P_j

$\eta\ (S_i,P_j)$: value of distance cost function from S_i to P_j.

Each ant must make a local update when building the different trajectories. Once the procedure is completed the ants must make a global update of the pheromone quantity. The following equation describes the local update process:

$$\tau_{ij} = (1-\rho)\frac{1}{tr_{ij}}^{old} + \Delta\tau_{ij}^{\ k} \quad (4)$$

$$\tau_{ij} = \sum_{k=1}^{m}\Delta\tau_{ij}^{k} = \begin{cases}\frac{Q}{L_k} \text{ if(ant k use the edge ij)} \\ 0 \text{ else}\end{cases} \quad (5)$$

ρ is the pheromone reduction parameter (0< ρ <1) depending on the information received from the RSu which concerns the traffic flow on a specific edge .The parameter m is the number of ants , L_k is the length of the round made by the ant k and Q is a positive random constant set at 100.

VI. Overview of the System Architecture

Our architecture (Fig. 2) is composed of a set of intelligent entities that will work together in a distributed manner to find the best solution for the driver, our distributed strategy for the parking routing problem is based on a set of agents with different behaviors:

- Parking sensors Agents: allow us to capture the information about the slots, and compute the number of available places on each parking.
- Parking profile agent: represents the intermediate between the cloud platform and parking sensors. It collects and shares all real-time data about the status of the parking spaces in each car park.
- Cloud communication agent: It ensures communication between agents using TCP/IP network communication. which allows our infrastructure to be distributed.
- Service agent: collects all real-time data and records it in NoSQL databases, we store information about each parking , service station and roads traffic such as : the coordinates of the parking, number of available slots, the coordinates of each service station, and the number of stopping cars in each road.
- Road sensor agent: allow us to recover the flow of traffic on a specific area based on the number of stopping cars between two intersections.
- ACO Agent: respond to the demand of the driver and find the optimal path to each driver request based on saved data. This agent is divided into two agents (the worker agent and controller agent)

- Worker agent: explores the road network, each worker agent (WA) will choose the next node to visit based on the value of the probabilistic transition. Equation 1 is based on two metrics which are the distance and traffic flow between two linked nodes. When WA completes the process of finding the solution, it finds the optimal path between the driver and an indoor car park with available spaces in a chosen area. At the end of the iteration, the optimal solution will be transmitted to the driver.
- Controller agent: he communicates with the cloud agent in order to obtain some information like (coordinates of each node, the distance and the traffic between two connected nodes, the amount of fuel in the driver's car) in order to send them to the worker agent.
- Driver agent: represented by an application that acts as intermediary between the driver and the parking routing system. The hybrid application is used to send a request for finding the optimal path toward an indoor parking and displaying the best path for the driver.

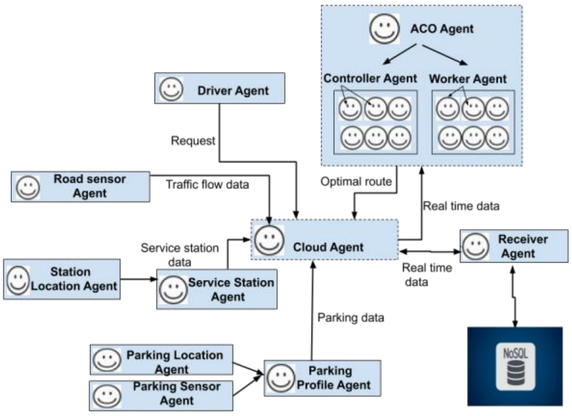

Figure 2. Distributed architecture based on ant colony optimization and multi agent system.

VII. Future Work

The proposed solution will be deployed using Java-Agent Development Environment (JADE). Firstly, the number of iterations and ants must be fixed. Each loop ends when a group of ants succeeds in finding a parking space in the chosen area. We will implement our distributed algorithm by defining the behavior of Worker agent that will provide the best path for the driver based on the given data stored in the cloud and the different constraints.

When the ACO agent receives a request for finding the optimal path, it will use the coordinates of the driver and the chosen destination to find the solution. Our solution will be implemented in order to compare it with the Particle Swarm Optimization method to see if our proposed solution is better in terms of the quality of the proposed solution, and also if our system consumes less time to compute the best solution.

At the end of each iteration, the ACO agent will be able to generate the optimal paths in terms of (Traffic, distance, time).

VIII. Conclusion and Perspectives

In this work, we have created a new parking routing system strategy based on the Internet of Things and a distributed ant colony algorithm to improve the quality of the proposed solutions. this solution aims to help drivers find the nearest parking spaces by taking into account a set of constraints such as the time to reach an indoor parking, the road conditions, the number of available spaces in each parking lot as well as the quantity of fuel in the vehicle, the proposed distributed architecture contains a set of distributed intelligent agents; each of them has a predefined behavior, these agents collaborate together in order to find the best and shortest paths between the driver's position and an indoor parking with available spaces. our system will be a useful solution for the driver to find the nearest parking space and give them the best path to go toward this parking based on the technique of ant colony optimization which is dedicated to solving the problem related to the vehicle routing system.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All the authors contributed as a team to this research work; and approved the final version.

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