Optimization for a Collaborative Delivery System

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Abstract - In recent years Unmanned Aerial Vehicles (UAV) have been used progressively in numerous civilian and military applications. Furthermore, there have been countless studies concentrating on the UAVs for their utilization in delivery systems, aiming at improving quality of delivery and reducing manpower. However, there are still many complications which require to be investigated. One of these complications is the inadequacy of flight time due to power insufficiency of small battery used in such systems, which results in the UAV failure to serve all customers directly from the main warehouse. To overcome this issue, a collaborative system between UAV and UGV is proposed. This system will deal with the optimization problem otherwise known as Vehicle Routing Problem (VRP) and the issue is solved by using the nearest neighbor heuristic algorithm. Moreover, MATLAB software is employed to implement the algorithm and simulate the system. The result shows that this system is faster than the system using a regular delivery truck.

Key Words: **collaborative between UAV/UGV, delivery system, VRP, nearest neighbor heuristic.**

1. INTRODUCTION

In recent years, the robotic technology has been increasing at a fast pace, which make robots more practical to do human- like works efficiently without any rest. A Multicopter is rotary craft type, of unmanned Aerial Vehicle (UAV). The chief feature of Multicopter is undoubtedly its ability to deliver cargo in a 3D space due to better maneuverability, simple mechanical structure and good relationship between total weight and payload capacity. Therefore, numerous studies conducted using the unmanned Aerial Vehicle (UAV) in the field of logistics. A study carried out by the National Aeronautical Centre (NAC) discloses that 42% of logistics' carriers shall consider in their business plans the utilization of UAVs for the distribution of cargo in the future. Also, the study concludes that 36% of "Freight Forwarders Surveyed" reckon UAVs will be used for the delivery of cargo [1]. Another study carried out by Raffaelo D' Andrea, who is responsible for the flying machine arena. He detailed some calculations to reach at the feasible expenses of drone delivery and he states that the operating costs directly linked with the drone are on the order of 10 cents for a 10 Km range and a 2 Kg payload. Furthermore, compare this with 60 cents per item, which we used over a decade ago in our trade plan for the total cost of distribution of cargo, so it is economically viable to deliver small packages by drone [2]. There are many logistics' companies that employ an aerial system for delivering cargo to customers, which will reduce manpower and also improve the quality of delivery. Amazon develops an aerial system for delivering packages to customers within 30 minutes of ordering. The order utilizes GPS and has to be small enough to fit in the cargo box and must be less than 5 pounds, also the delivery spot should be within a ten mile (16 Km) radius, at speeds of up to 50 mph (80.5 km/h) and the packages weighing up to 5 lb. (2.26 kg) [3]. In September 2014, DHL started using UAV for the delivery of important packages such as medication, between a harbor on mainland Germany and a small island called Juist, for a distance of 12 Km. The UAV can carry a payload of up to 1.2 Kg at a maximum speed of 65 km/h. The UAV can complete its mission in 15 to 30 minutes, depending on the weather conditions [4].

Consequently, it is a clear insight, that is in order to make the cargo delivering efficient, effective and faster, the UAV is an ideal candidate to solve this problem. This is due to a single point hover, high maneuverability, vertical takeoff, landing, and the ability to carry loads ranging from 50% to 100% of their body weight [7].

Moreover, using UAV in the delivery system is still in its early stage, and there are numerous difficulties which need to be investigated. One of such difficulties is related to the upper limit of parcels that the UAV can carry due its small size. This means that the UAV has to return to the depot after each delivery, which is not very efficient. Furthermore, the UAV is battery powered so the flight time is obviously limited. Consequently, not all customers can be served directly from the main warehouse. On the other hand, the regular delivery truck has a long operation time and carry many parcels, but it is heavy and slow as shown in table (1).

optimization which, articulated as an integer programming problem and it aims at serving a number of customers with vehicles, at the minimum possible cost. First the mathematical formulation will be represented for one scenario, using more than one UAV and one UGV. Next the consistent algorithm will be utilized to solve the problem.

Finally, a comparison between these systems and the regular delivery truck will be discussed to demonstrate that this system is more efficient, effective and faster.

Table-1: comparison between truck and UAV.

	Capacity	Speed	Weight	Operation time
Truck	High	Low	Heavy	Long
UAV	Low	High	Light	Short

1.1 Related Literature

There is a large amount of studies working on the traveling salesman problem (TSP) and vehicle routing problem (VRP). Although not all these foundational problems are directly applicable to the problem at hand, only some studies are directly related to our problem. The vehicle routing problem (VRP) is the problem related to distribution of goods between depots and customers [8]. The traveling salesman problem (TSP) is a special case of the VRP. For more detail and an overview of the vehicle routing problem and TSP, types, formulations and solution procedures see books [8] [9], and studies [10] [11]. In the [12] the researchers at the university of Cincinnati and AMP electric vehicles have worked to develop a delivery truck-drone system work for parcel delivery. The system is a collaborative between the electric truck and drone. The truck driver can make the delivery on the main route while the drone serves other customers one by one and returning to the base (truck) after each delivery to pick up another parcel. In the [13] the AMP electric vehicle works for testing a new collaborative system between the electric vehicle and UAV to deliver parcels that are outside of the main delivery route of the truck. The UAV is loaded with parcels and takes off to make the delivery and in the same time the truck will continue on its journey. After the UAV completes the delivery it will fly back to the truck for next delivery and also for recharging its battery. In [14] and [15] the authors have developed a new mixed integer linear programming formulation for a collaborative system between a drone and a delivery truck called "Flying Sidekick Traveling Salesman Problem" (FSTSP) and "Traveling Salesman Problem with Drone" (TSP-D) respectively. In [14] two problems are studied, the first one where the depot is out of the UAV's flight range. Therefore, the customers are served by delivery truck unless some of them are served by drone. In the other problem, the customers are served directly from the warehouse and only some of them are out of the UAV's flight range, therefore, delivery truck will serve them as well. An efficient heuristic algorithm was utilized to compute the solution of two problems and to compare with the delivery truck only. The delivery time is reduced when used the collaborative system. [15] It is similar to the FSTSP and the only difference is that the authors assume that the drone and truck travel on the same road which allows to develop a heuristic algorithm with approximation guarantees. The two previous studies are quite similar to our problem where they proposed a collaborative system between a truck and drone and used a heuristic algorithm to solve the problem, however, the formulation is different in the problem as the previous studies used mixed integer programming formulation. Mixed integer programming is needed when the problem involves both routing and missions resolving. Mission resolving is required to determine which vehicle, truck or drone, will serve which customers, and routing resolving is required as well to determine in which sequence the customers on each vehicle are visited. Since our problem is VRP and all customers will service by UAV only, integer linear programming is used to formulate it and the nearest neighbor heuristic will be used to solve it. The other difference that is obvious here, is that we use the UGV as a sub warehouse to solve the limited flight time problem of UAV, in addition, this will make the delivery system more automated.

1.2 Problem description

The use of Multicopter in the delivery system directly from the main warehouses is practically inappropriate due to limited flight time. Furthermore, there is another difficulty which is the warehouse should be very close to the customers, which means that there is a need to construct a new warehouse closely to the customers, as shown in figure (1). There are n customers served by Multicopter, the Multicopter loaded from the warehouse with cargo and delivered to customers, but some customers cannot be reached by UAV due to long distance between them and the warehouse also due to the limited battery capacity of Multicopter which impacts the flight endurance. So the solution to these problems is to develop a collaborative system between the Multicopter and UGV. Accordingly, the UGV is freighted with cargo (things to be distributed) from the central warehouse and in the same time the Multicopter is carried by UGV. When serving demands of customers the Multicopter takes off to do the delivery task and after completing the mission, it returns back to land on the UGV. The UGV will work as a sub warehouse and can be close to the customers. While the Multicopter is in the base the new shipment will be loaded and at the same time the battery will be charged or replaced in order to be ready for the next mission. We proposed a scenario in which the unmanned aerial vehicle, distribute the cargo to customers in the urban last mile with help from the unmanned ground vehicle. The goal is to minimize the traveling distance and the time of delivery service and there are numerous of constraints that should be taken into account.

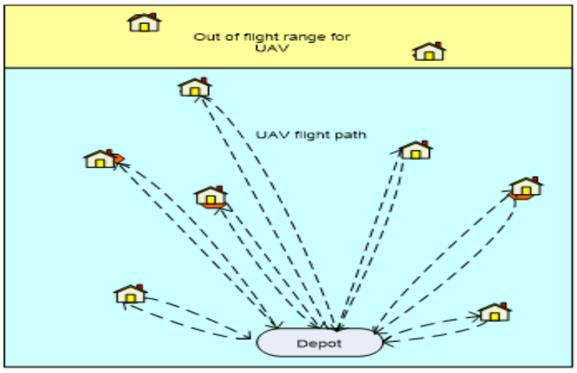


Fig-1: The UAV is delivered to all customers from the warehouse within the UAV's flight range, some customers out of flight range.

In this scenario, the system may consist of one or more than one Multicopters and one UGV. The system considers a set of n customers each of them must be served accurately once. The UGV is loaded in distribution center by parcel which will be delivered to the customers and carries an UAVs. The customers will be represented by **n** nodes and node **n+1** added for UGV. When the UAVs starts the service from node n+1 (UGV), there is more than one path. Each path starts and ends in the UGV node and serves n customers as shown in figure (2). The Multicopter has limited flight time and a maximum loading capacity. This problem is known as a vehicle route problem and solving this problem will reduce the delivery time and improve the efficiency of the system.

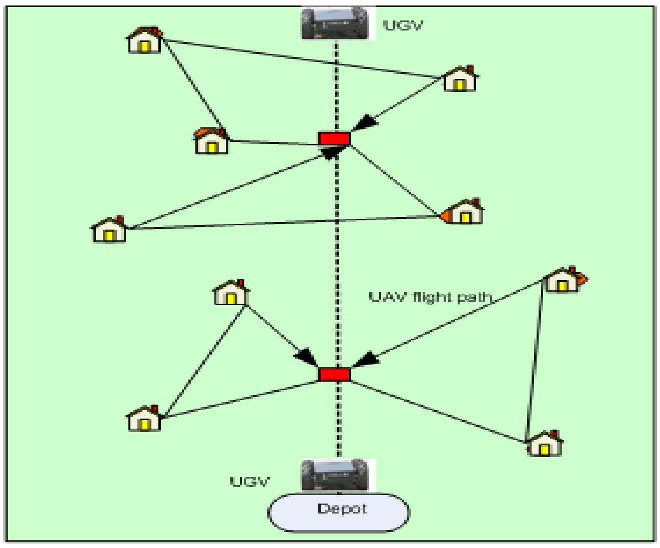


Fig-2: Optimized delivery system by using UAV and UGV to serve all customers.

The Multicopter should leave and return back to the same point (UGV) exactly once. Over the delivery cycle the Multicopter might do many flights, each consists of three locations or more. The Multicopter begins the flight at the base on the UGV (where it is loaded with, a parcel for a customer). A service time may be required before launching to replace or charge the battery and to load the parcel. The second location in the flight must be a customer that is served by the Multicopter. It may serve more than one customer and it depends on endurance time and payload. The final location of the flight is the base on the UGV. Therefore, the flight time of the UAV should be within the UAV's flight time limit. The objective function is to minimize the time required to serve all customers.

2. Model formulation

The vehicle routing problem (VRP) is becoming one of the most important topics in logistics and it deals with minimizing the total cost of logistic system. The formal definition is given as the graph theoretic models. To find the mathematical formulation, the following parameter notation is utilized by the integer linear programming.

2.1 Notation

G = (V, A): is a complete graph where V is a vertex set (nodes) and **A** is the arc set (paths between nodes). The vertices **V** = 1,....., n corresponding to the customers, the depot, which in this case the UGV is associated with n_{+1}. Let C= (c_{ij}) be a cost matrix (distance) associated with A. The matrix C is said to be symmetric when $c_{ij} = c_{ji}$, $for\ all\ \forall(i,j) \in A$, and asymmetric when $c_{ij} \neq c_{ji}$, $for\ all\ \forall(i,j) \in A$.

X_{ij} : is the decision variable. It is equal to 1 if the vehicle travel from node i to node j and is equal to 0 otherwise.

c_{ij} : is the travel cost spent to go from i to j with each arc $(i,j) \in A$. It is considered as the distance for travelling from node i to node j.

N : is the set of all nodes in the network, it is denoted as N = {1, ... ,n}.

M : is the maximum number of unmanned aerial vehicles that can be used.

T : is the endurance time, which is exactly the maximum route duration time for the vehicle. This time consists of the time of service t_i and the traveling time from node i to node j (customer).

Q : is the maximum capacity can be the Multicopter carried.

B : is the maximum energy capacity of the battery

The objective function is to minimize the route length, which is the total traveling distance to serve all customers:

$$\min = \sum_{i \in A} \sum_{j \in A} C_{ij} X_{ij} \quad (1)$$

Subject to:

$$\sum_{\substack{i=1 \\ i \neq j}}^{N} X_{ij} + X_{N+1,j} = 1, \forall j \in N \quad (2)$$

$$\sum_{\substack{j=1 \\ j \neq i}}^{N} X_{ij} + X_{i,N+1} = 1, \forall i \in N \quad (3)$$

$$\sum_{j=1}^{N} X_{N+1,j} = m \quad (4)$$

$$\sum_{i=1}^{N} X_{i,N+1} = m \quad (5)$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} (C_{ij} + t_i) X_{ij} \leq T \quad (6)$$

$$\sum_{i \in A} \sum_{j \in A} C_{ij} X_{ij} \leq L \quad (7)$$

$$X_{ij} = 0{,}1 \quad \text{for all} \quad (i, j) \in A$$

Constraint (2) guarantees that each customer is reached from either the depot or from another customer. Constraint (3) guarantees that from each customer, we go to another customer or to the depot node. Constraints (2) and (3) ensures that each customer is served exactly once. Constraints (4) and (5) guarantee that exactly m vehicles depart from and return back to node n+1 which represents the UGV. Constraints (6) guarantees that the travelling time and service time at each customer is not encroaching the maximum route duration time T. Constraints (7) guarantees that the vehicle's travel distance cannot exceed the maximum travel distance L.

Due to the limited battery capacity of Multicopter, the energy consumption must be taken into account. So to travel between two points, it is necessary to find the minimum energy consumption paths. To reduce the energy consumption for the Multicopter, there are some characteristics that should be considered, such as that payload, speed of the vehicle and the environment conditions. In this study, we only add the constraints of energy consumption to ensure the Multicopter will complete its mission and avoid entering into the crashed state.

$$0 \leq y_j \leq y_i - (r.c_{ij}) X_{ij} + B(1 - X_{ij}) \quad (8)$$

$$y_i \geq \min(r.c_{i,n+1}) \quad (9)$$

The constraint (8) represents the level of charge of the battery, y_j is the current energy available and it has to be smaller than the previous current energy y_i , and (r) is the energy consumption per Km/mile when, the vehicle is travelling from a customer node to any other node.

The constraint (9) guarantees that there is enough remaining energy to return to the base. Both constraints guarantee that the available energy is always positive in any nodes. B is the maximum energy capacity of the battery.

3. NEAREST NEIGHBOR HEURISTIC ALGORITHM

Most of vehicle routing problems are not solved optimally in reality because the solution is growing exponentially with the number of customers. Suppose there are **n** customer to be served by one vehicle. Then the total number of feasible solutions is (n-1)! Which grows exponentially [16]. For **n** = 5 the feasible solutions are 24 while, for **n** = 8 the feasible solutions 5040. There are many methods to solve the VRP, exact, approximate and simulation. The exact method guarantees that the optimal solution is found, but it is suitable only for the small size problem. Normally, branch and bound algorithm used to provide exact solution. A heuristic method is a procedure that is possibly used to discover a very good feasible solution. However, not necessarily an optimal solution. The main advantage of the heuristic method is their speed and ability to handle large problems. Simulation method is still in an early stage of implementation. It can effectively handle the problem of the complex system. It is used when the problem size is grown up.

The nearest neighbor heuristic, is a simple approach for solving the VRP. It was one of the first algorithm used to determine a solution to the VRP. The algorithm starts at the node n_{+1}, and repeatedly visits the nearest nodes until all have been visited. It quickly yields a short tour, but usually not the optimal one [17]. The procedure of the nearest neighbor heuristic algorithm with many constraints is shown in a chart (1).

For our problem, first the nearest neighbor algorithm is utilized to solve a problem with n=5 and n=10, for symmetric cost matrix utilizes a truck. The distances between customers are shown in figure (3) for n=5. Consequently, MATLAB software is utilized to find the minimum cost for the Multicopter to serve all customers and return back to the base.

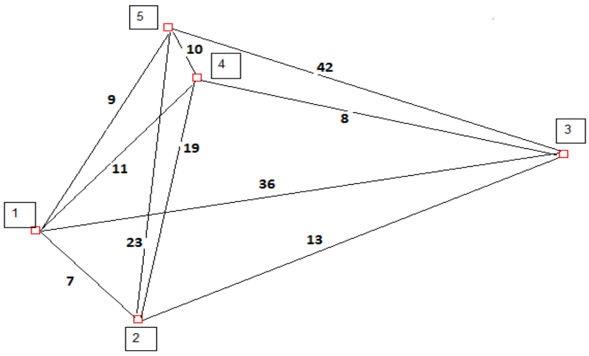


Fig-3: The distance between customers for n = 5 and symmetric matrix.

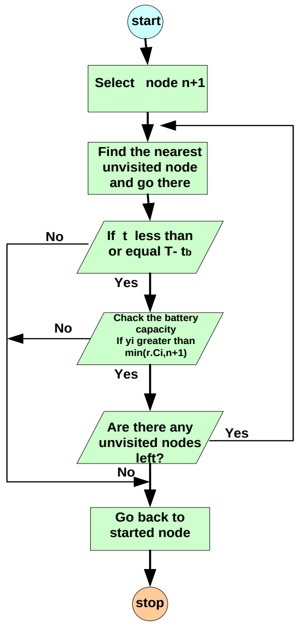


Chart -1: Flowchart for nearest neighbor algorithm

4. SIMULATION AND RESULT

The solution for n=5 is shown in table (2) and the shortest tour is shown in figure (4). The short distance traveled is 47 m for all tours, as a result, the truck starts from any node and it will be the same distance traveled.

Table-2: The path and distance for N =5 symmetric customers.

Tour No	Paths	Distance Traveled
1	1→2→3→4→5→1	47
2	2→1→5→4→3→2	47
3	3→4→5→1→2→3	47
4	4→3→2→1→5→4	47
5	5→1→2→3→4→5	47

For n=10 the location coordinates of customers are shown in table (3) and the shortest path is shown in figure (5). The route is starting from node 10 and serves all customers and returns back to the start node as: 10→9→8→5→2→3→4→6→1→7→10 whit minimum distance 90.72 Km.

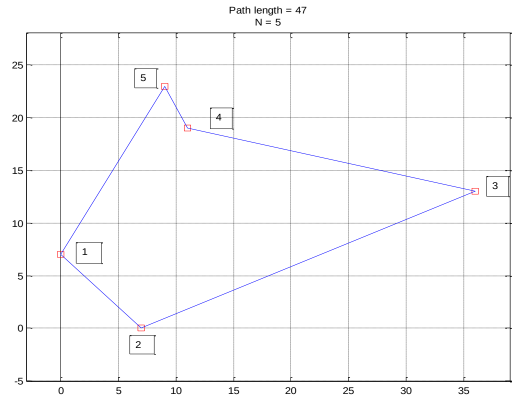


Fig-4: The shortest tour for symmetric problem and n = 5

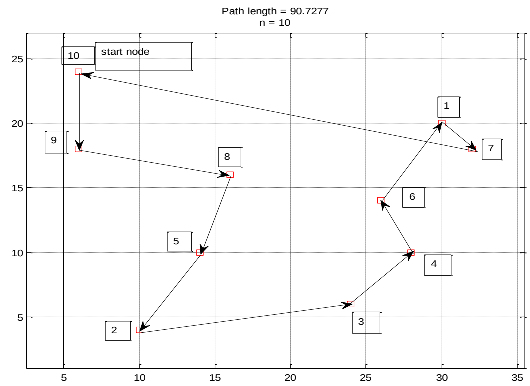


Fig -5: The shortest tour for problem with n = 10 used truck

The solution above is appropriate for delivery truck and not suitable for Multicopter due to limited flight time and maximum capacity of Multicopter. Therefore, the next step is to add constraints and solve the problem to compare it with this solution.

To use the Multicopter for delivering cargo, we have to consider the system under some assumptions:

- The parcel is small, so the UAV can serve more than one customer.
- The UAV can fly direct without any obstacles in its way.
- The weather condition will not be considered.

From [3] and [4], the maximum distance the UAV can travel is about 30 Km in 30 minutes, so the energy consumption per Km from the full charge battery can be calculated as:

$$\frac{\textit{full state of charge}}{\textit{maximum distance traveled}} = \frac{100}{30} = 3.333\%$$

The energy consumption per Km is 3.333 % from the FSOC.

Two cases are considered, first one, is that the UAV will serve ten customers. The Location coordinates of the customers are shown in table (3)

Table-3: Location coordinates of the customers

Number of customers	*x*-coordinate /km	*y*-coordinate /km
1	15	10
2	5	2
3	12	3
4	14	5
5	7	5
6	13	7
7	16	9
8	8	8
9	3	9
10	3	12

The solution is shown in figure (6) and table (4). Started from node 8 the UAV can serve all the customers with three tours and return to the same node. In each tour, it served three customers. At the end of each tour the UAV will land on UGV to change the battery and load on next parcel. Figure (7) shows the distance traveled and the state of charge SOC at every customer for each route.

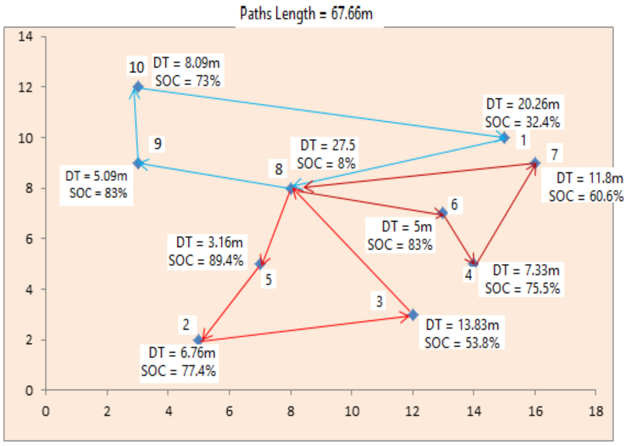


Fig-6: Distance traveled and the state of charge SOC for n=10

Table-4: Tour No. and distance traveled

Tour No	Path	Visited nodes	Distance Traveled
1	8→5→2→3→8	3	20.24
2	8→6→4→7→8	3	19.86
3	8→9→10→1→8	3	27.54

To compare between the Multicopter and truck, the time required to serve all customers is calculated. We assume the speed of the UAV is 80 Km/hour, and the maximum flight time is 30 minutes, so to travel one Km the time required is 0.75 min. The time required for service cycle starting from the base (UGV)

$$t = t_r \, c_{ij} + t_i \tag{9}$$

Where c_{ij} is the distance traveled from customers i to j, and t_i is service time at customer i and its equal to one minute. t_r, is the time rate to travel one Km.

For the truck, we assume the maximum speed is 40 Km/hour, so to travel one Km, the time required is 1.5 min. Also, the service time is assumed 2 min. From equation (9), we can compute the time required to serve customers by truck and the result is shown in table (5) and (6).

Table -5: Compare the delivered time between UAV and truck (three UAVs for three tours)

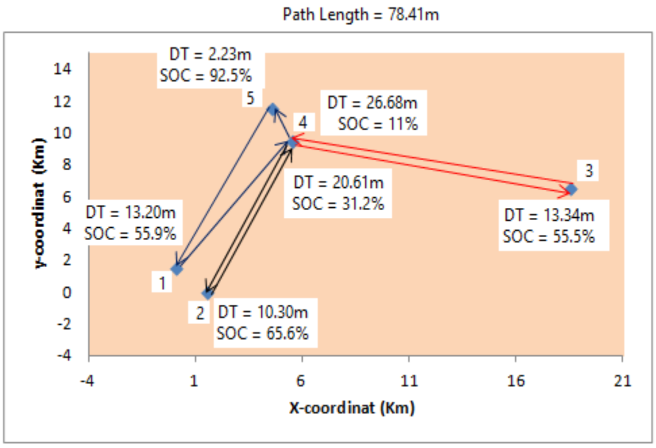
Customers	Delivered time by UAV min.	Delivered time by truck min.	Average delivered time by UAV	Average delivered time by truck
1	31	93.8	14.53	59.84
2	11.15	46.6		
3	21.75	67.8		
4	12	76.29		
5	5.74	35.78		
6	8.64	83		
7	18.7	98		
8	0	26.29		
9	8.64	11		
10	13.14	0		

From the result, we see that the average time for delivery by using Multicopter is less than by using truck if we use only one Multicopter to serve all customers in three routes. On the other hand, if we use three Multicopter for three routes the average time will be much lower than in the previous case. Therefore, the use of Multicopter in the delivery system is better and it makes the delivery process faster than using the truck.

Table -6: Compare the delivered time between the truck and UAV (one UAV for three tours)

Customers	Delivered time by UAV min.	Average delivered time by UAV	Average delivered time by truck
5	5.74	51.64	59.84
2	11.15		
3	21.75		
8	31.36		
6	40.01		
4	43.36		
7	50.07		
8	62.16		
9	70.81		
10	75.31		
1	93.56		
8	104.48		

The second case, the Multicopter will serve five customers, the result is shown in figure (7) and table (7).



Figu-7: Distance traveled and the state of charge SOC for n=5

Table -7: Tour No. and distance traveled

Tour No	1	2	3
Path	4→5→1→4	4→2→4	4→3→4
Visited nodes	2	1	1
Distance Traveled	22.91	20.61	26.68

From the figure above, we see that the UAV starts from node 4 and it's the best solution to service all customers with minimum distance. Due to long distance between some customers, it serves only one customer in two routes.

5. CONCLUSION

In this study, a collaborative system between the Multicopter and UGV using in delivery system was presented. This system was modeled as an optimization problem called vehicle routing problem and solved by using a nearest neighbor heuristic algorithm to compute the shortest tour for Multicopter by taking into consideration the limited battery capacity. The average delivery time also is calculated and the solution shows that the average delivered time by UAV is faster than the average delivered time by truck and this make the UAV more appropriate for delivery system than regular truck. The solution also shows the shortest route for the UAV to serve all customers by taking into consideration the state of charge of the battery. The next step is to improve the algorithm by adding the e nergy efficiency issue and analyzing the relation between the vehicle capacity and energy consumption.

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