Multi-UAV Employed Secure Parcel Delivery System using Blockchain

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***Abstract*—The optimization of parcel delivery services to consumers has become a priority due to the rapid development of the logistics industry, particularly in relation to the primary application of Industry 4.0. It is difficult to maintain trust between a travel company and its consumers. Although many of the current solutions identified in the research address trust issues, most of them are based on centralized architectures, such as cloud computing, where data is vulnerable to a variety of security threats. In this article, a multi-UAV-based secure parcel delivery system using blockchain has been proposed to increase trust among entities. Moreover, genetic algorithms (GA) are exploited to generate routing paths for multiple heterogeneous UAVs. Initially, optimizing fitness function, selection, crossover, and mutation operators are generated by utilizing the GA. The novelty of this research is to propose a secure delivery system using GA for heterogeneous multiple UAVs. Finally, the GA method is constructed to optimize the time constraint issue, and different consensus mechanisms are scrutinized to verify the performance (e.g., latency and average transaction) while storing the parcel delivery information in the blockchain network.**

***Index Terms*—Blockchain, Delivery System, Genetic Algorithm, Unmanned Aerial Vehicle, Vehicle Routing.**

I. Introduction

Unmanned aerial vehicles (UAVs) are currently utilized in numerous industries, including construction, surveying and mapping, security, aerial video recording, energy and utilities, public protection and emergencies, transportation and infrastructure, mining, and the delivery of parcels. [1] [2]. Nowadays, UAVs can function independently, much like smart robots. This makes them capable of performing tasks that would normally require human involvement [3]. Today's commercial UAVs are outfitted with a variety of self-managing autonomous functions, making them capable of carrying out activities such as landing and navigation without the need for human intervention [4]. Considering this, there are still some functions that need to be supervised by a person [5].

There are three primary focuses while deploying UAVs for delivery services. (1) Consumers, (2) Manufacturers and distributors of commodities, and (3) Logistics providers [6]. Additionally, multiple researchers have attempted to address the issues for UAV-based parcel delivery systems [7]–[9]. Joanna et al. [10] presented a genetic algorithm (GA) based system to solve vehicle routing problems. The authors employed multiple UAVs with the same capability. However, it would be more beneficial if heterogeneous UAVs can be deployed—for example, small UAVs for short-distance delivery and large UAVs for long-distance delivery. A large UAV or a small UAV can be chosen for a specific assignment depending on factors such as range, payload capacity, endurance, and operational environment. Large UAVs typically have powerful engines or propulsion systems, which may run on petroleum or jet fuel [11]. These engines produce more energy, enabling the UAV to carry greater payloads and travel farther distances. Due to their smaller size and weight, small UAVs are typically only driven by electric batteries [12]. These batteries can be charged and provide the energy needed for propulsion and other onboard systems.

Therefore, this paper will investigate the implementation of GA to the vehicle routing problem involving multiple UAVs with different capabilities to reduce the cost of procuring UAVs and optimize their utilization. Moreover, GA will provide the fastest parcel delivery times considering the utilization of UAVs for each delivery. Furthermore, there is a lack of consideration of the security aspect or guarantees regarding the performance of the multiple heterogeneous UAVs for parcel delivery systems in the existing literature. For instance, the UAV must travel through the designated path, and the parcel should be delivered securely to its destination.

In addition, a secure system is required to maintain the confidentiality between consumers and sellers in an automated parcel delivery system. Therefore, a blockchain-based secure parcel delivery system is developed in this article. The blockchain is a distributed and decentralized ledger that protects the information to avoid third-party interaction [13]. It is possible to utilize the blockchain to improve the transparency and safety of aerial communication networks (Figure 1), as well as to ensure the dependability of the data. Because blockchain technology provides security in numerous sectors such as the Internet of Things (IoT) [14], AI [15], the coupling of blockchain technology and UAVs can be beneficial to make a more powerful and autonomous system.

The contributions of this paper are mentioned below:

- A genetic algorithm (GA) is exploited to generate a routing path for multiple UAVs.
- Moreover, a blockchain-based secure parcel delivery system has been developed for multiple heterogeneous UAVs.
- Finally, result analysis has been concluded to show the efficacy of the proposed model.

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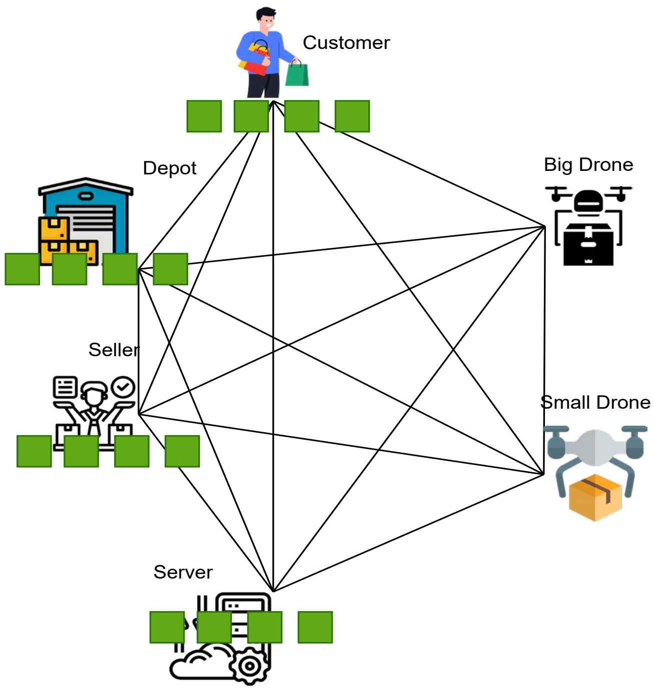

Fig. 1. Blockchain models.

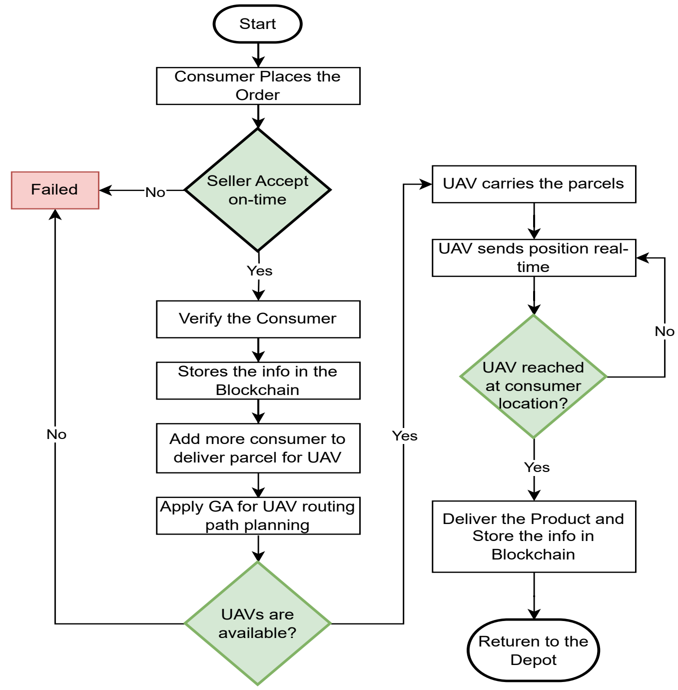

Fig. 2. Flowchart System

II. System Model

During the process of delivering a package from the depot to the consumer, several steps must be implemented to ensure that the parcel follows the consumer's order and reaches the correct consumer. The flowchart of the proposed system is explained in Fig 2. The initial step for consumers is to place an order. Then, the seller verifies the consumer and stores the ordered items in the blockchain network. Then, the consumer location is transferred to the UAV for delivering the parcel. The GA is applied in this model to determine the best routing path for the UAVs to send parcels.

We describe the model in the section II-A to determine the process of routing parcels using UAV. If the consumer's request cannot be fulfilled due to the limited number of UAVs, the consumer will be notified that the delivery process cannot proceed. If the results of the UAV routing show that it is capable of fulfilling consumer requests, the parcel will be delivered by the UAV.

At this stage, it must be guaranteed that the UAV has obtained the correct destination information and is following its planned route after applying the GA. As long as the UAV is in flight to deliver the parcel, the seller and consumer will receive real-time updates on its location. After the consumer receives the parcel from the UAV, it will send a notification to the depot and update the delivery information in the blockchain registry.

A. Routing Delivery

The number of consumers, consumer locations, number of available UAVs, maximum payload, and maximum mileage for each UAV are required for parcel delivery routing. In Fig 3, it can be shown that the different sizes of UAVs can carry out different numbers of parcels. In this system model, it is assumed that large UAVs can carry more than two parcels in one flight, and small UAVs are only able to carry one parcel in one flight.

The value of the variable uav_{ij}^{k} is used to find a decision. If the value of uav_{ij}^{k} is *1*, that means there is a trip from i to j. If the value is 0, it means there are no trips from i to j.

$$uav_{ij}^{k} = \begin{cases} 1, & there\ is\ a\ trip\ from\ i\ to\ j \\ 0, & else. \end{cases} \tag{1}$$

Only a single visit is permitted for the UAVs to visit each consumer. After the consumer is served, the UAV uses one of the routes to go back.

$$\textstyle\sum_{k=1}^{m} \sum_{i=0}^{n} uav_{ij}^{k} = 1, \forall j \in \{1, 2, \ldots, n\} \tag{2}$$

The UAV's parcel delivery capacity (U) with a given path in a single flight is computed by accumulating the orders of every consumer (q_j) along the route.

$$\textstyle\sum_{j=0}^{m} q_j \left(\sum_{i=0}^{n} uav_{ij}^{k}\right) \leq U, \quad \forall k \in \{1, 2, \ldots, m\} \tag{3}$$

The cumulative travel time of each UAV Z must be less than the maximum allowed (T_{max}) time. In addition, the total UAV service time is calculated by adding the travel times required to visit each consumer along a given route. .

$$\textstyle\sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij}^{k} uav_{ij}^{k} \leq T_{max}, \quad \forall k \in \{1, 2, \ldots, m\} \tag{4}$$

The Euclidean distance is exploited for computing the distances between consumers, with the distance from i to j being equivalent to the distance from j to i.

$$\textstyle\sum_{j \in N} uav_{ij} = \sum_{j \in N} uav_{ji}, \forall i \in N \tag{5}$$

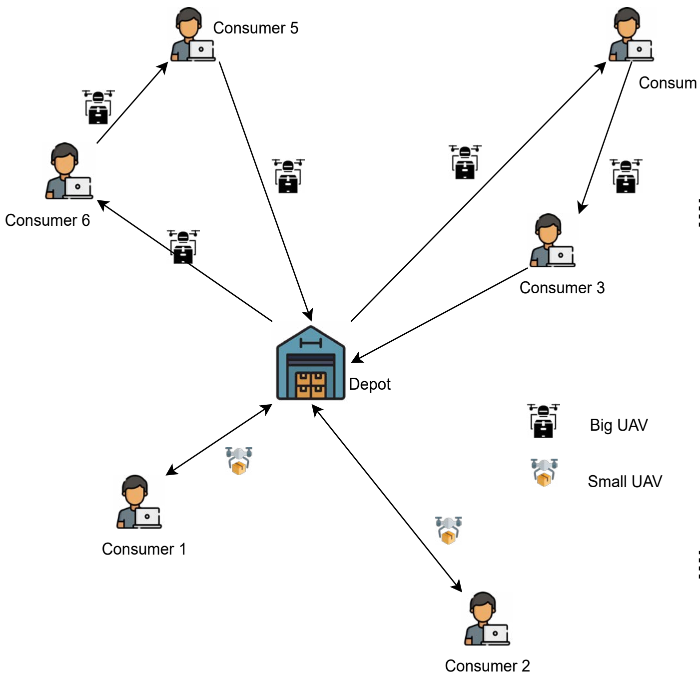

Fig. 3. Model of UAV Routing Delivery

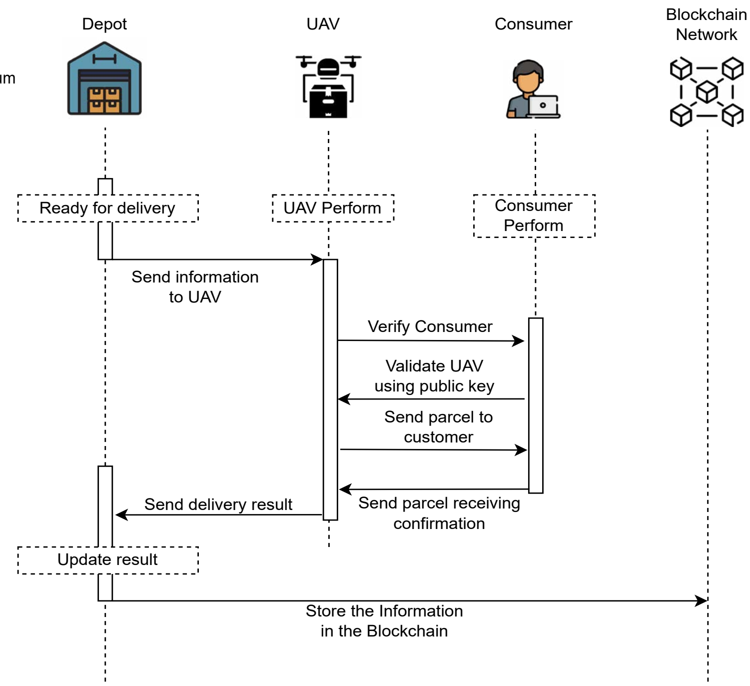

Fig. 4. UAV delivery process

$$d(x, y) = \sqrt{\sum_{i=1}^{n} (y_i - x_i)^2} \tag{6}$$

The UAV's travel duration from location i to j (t_{ij}) can be calculated by dividing the distance between them with the speed of the UAV (S_d):

$$\sum_{i \in N} t_{ij}^{k} = \frac{d_{ij}}{S_d}, \forall j \in N \tag{7}$$

The GA was initially created as a computing method that operated on a population of potential solutions to a specific problem [10]. The operators that were represented in the study included selection, reproduction, and mutation. The process of selection guarantees that people with superior behaviors have a higher likelihood of successful reproduction. In contrast, offspring were produced through the process of reproduction, wherein segments of one solution were combined with segments of another solution. Finally, the process of randomized mutation was implemented, typically including the exchange of two bits or the negation of a single bit inside an individual across the entire population.

B. Blockchain Model for Parcel Delivery

In the Internet of Things (IoT) environment, cryptographic methods can be used to secure UAV-to-everything (U2X) communication. However, as the UAVs are equipped with limited resources, it is unable to fly longer distance, and the communication range is short. However, the underlying concept of blockchains could be effective in the development of an appropriate security mechanism for the Internet of Drone Things (IoDT) [16]. The nature of blockchain is decentralized. Therefore, the data that is recorded into a block is unchangeable. Moreover, one of the most significant benefits of blockchain technology is the ability to operate independently without any third-party involvement. It is beneficial to IoTD because it will ensure the decentralization of the ecosystem while also protecting the security of the densities engaged.

Based on Fig 4, the proposed secure delivery process is described as follows:

- The UAV collects the secure parcel delivery information from the depot, including the consumer's order quantity and delivery location to hand over the parcel.
- The UAV flies to the parcel delivery location and then initiates communication with the consumer's device using public key cryptography.
- In public key cryptography, each device has one public key and one private key. It is assumed that all the devices are registered in this system so that they can communicate with each other using public key cryptography.
- Once the consumer gets their parcel, it sends a confirmation message to the UAV.
- After delivering the parcel and getting the confirmation from the consumer, the UAV sends the delivery confirmation to the original depot. Then, the depot stores the information in the blockchain network.
- In the event of a failure in the verification process between the UAV and the consumer's device, the delivery will be canceled, and the outcome of this situation will be properly recorded.

III. Result and Discussion

A. Routing Path Generation of the UAV

This section will explain how multiple heterogeneous UAVs can deliver parcels. UAVs are focused on flight range and payload capacity (U). A large UAV can deliver products directly to two locations during a single flight. A small UAV can deliver one parcel in one flight, with near travel distance. In our experiments, we employ two large UAVs and two small UAVs, with a total of ten consumers. Fig 5 shows the GA results based on Algorithm 1.

Algorithm 1 Genetic Algorithm

$Input \leftarrow$ Consumer Location, Number of UAV, U
$Output \leftarrow routing$
Randomly generate the initial population
Compute Fitness
repeat $Routing$
    Selection
    Crossover
    Mutation
    Compute Fitness
until Best individual has converged

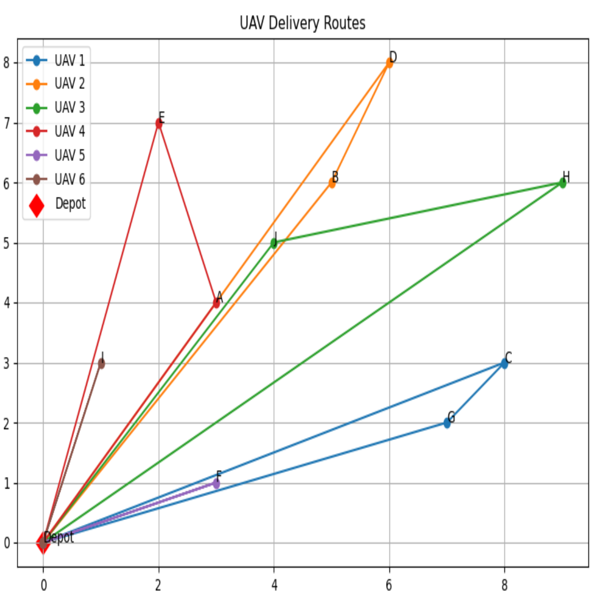

Fig. 5. Routing UAV with GA

In Fig 5, the total number of UAVs is four, consisting of two large UAVs and two small UAVs. Due to the difference between the number of consumers and the total number of UAVs, it became necessary for two large UAVs to perform two missions simultaneously. Upon completing the first delivery, the UAV returned to the depot and proceeded on another flight to deliver a parcel to a different consumer.

Fig 6 displays the graph illustrating the relationship between iteration and distance. There is a positive correlation between the number of iterations performed and the likelihood of attaining the maximum value.

B. Latency Analysis of the Blockchain Network

In this section, blockchain performance is analyzed based on the two performance metrics. Latency analysis and

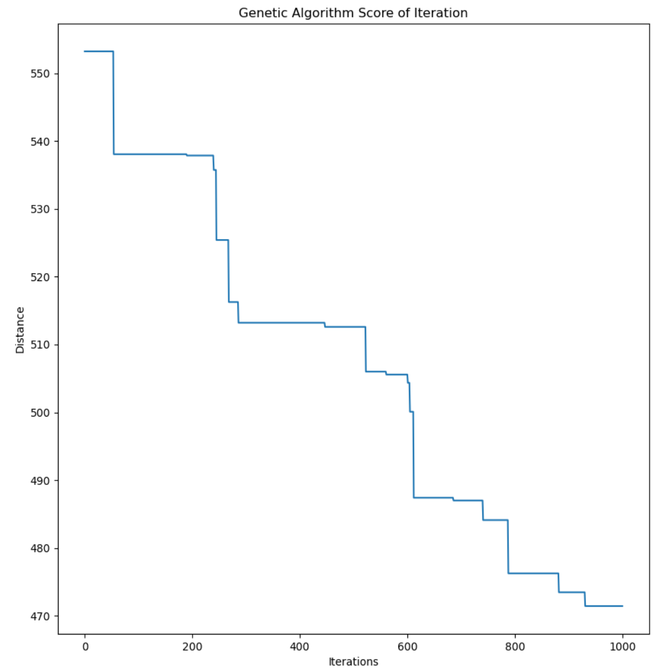

Fig. 6. Output of routing iteration

TABLE I
IMPLEMENTATION ENVIRONMENT

Implementation Environment	
OS	Windows 10
Blockchain	Private Ethereum Network
Client	Go Ethereum
Consensus	Proof-of-Work, Proof-of-Authority
Node	1-3

Transaction-per-Second (TPS) analysis. The implementation environment is shown in Table I.

Latency is defined as the time it takes for every transaction to be included in the blockchain network. Fig 7 represents the latency of each consensus according to the number of mining nodes. The average latency of one Proof-of-Works (PoW) mining node is 2372 milliseconds while storing the data, greater than the other mining nodes. PoW takes a lot of time because of the competition to solve mathematical puzzles before the transaction can be included in the blockchain network. This behavior leads to lower computation (number of nodes), and a lower chance of solving the mathematical puzzle that leads to the higher latency. Moreover, as shown in Fig 7, the PoW with two mining nodes has a higher latency at 300 transactions compared to one mining node. Moreover, the latency of PoW-based consensus is fluctuating more compared to the Proof-of-Authority (PoA) consensus algorithm.

In PoA-based consensus, the latency is more stable because it does not relate to the chance of solving mathematical puzzles. In PoA, it is based on a fixed period of block generation. In this case, the PoA latency in Figure 7 until 500 transactions is around 1000 - 2000 ms. Due to the specified period of block generation, the latency also shows a reduced mean value of around 1000 ms for every PoA mining node. In terms of latency performance, it can be shown that a private

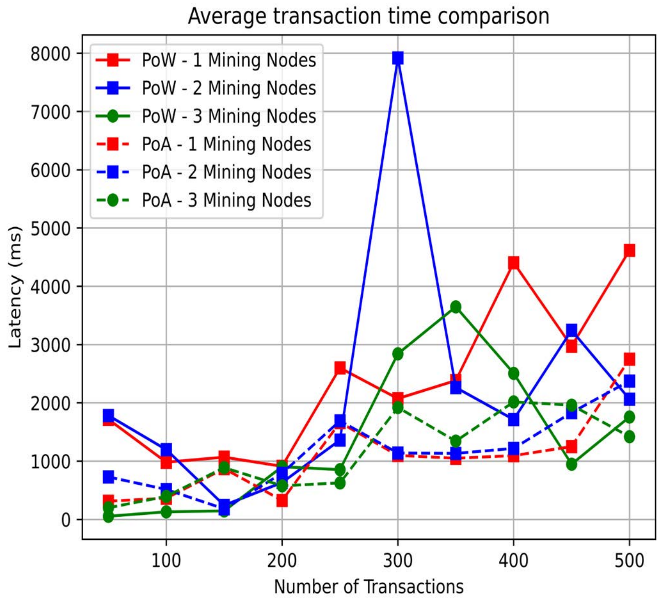

Fig. 7. Blockchain latency over number of transactions.

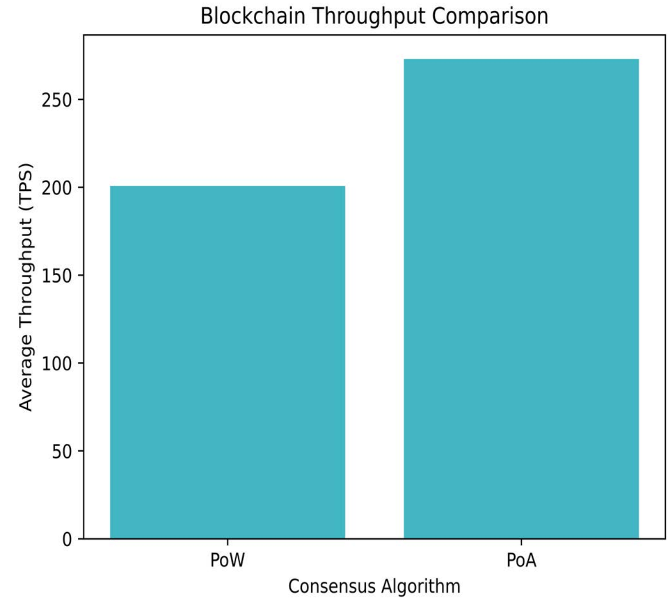

Fig. 8. Average TPS of each consensus.

blockchain network utilizing a PoA consensus mechanism is more suitable for facilitating real-time data transactions in UAV scenarios compared to a PoW network.

C. TPS Analysis of the Blockchain Network

The result of TPS is shown in Figure 8. TPS is defined as the number of transactions that can be recorded on the blockchain in one second. The translation of TPS can be represented mathematically in the form of an equation as follows:

$$TPS = \frac{T_{block}}{B_{time}}, \tag{1}$$

with T_{block} defined as the average number of transactions in one block and B_{time} defined as the average block time.

In the private blockchain network simulation, PoW and PoA can record 273 transactions in one block. In the context of consensus algorithms, it is observed that the average block generation time for PoW is approximately 1.56 seconds, whereas for PoA, it is around 1 second. This variation is related to the fixed-period structure of the PoA consensus mechanism. Based on Equation 8, the value of TPS for each consensus algorithm is calculated, as shown in Figure 8. In the PoA TPS case, the block generation time is not the same as in the PoW case. Therefore, PoA is recommended for utilization in the proposed multi-UAV-employed secure parcel delivery system.

IV. Conclusions and Future Work

In this study, a multi-UAV-employed secure parcel delivery system using blockchain has been proposed. The genetic algorithm (GA) is implemented successfully in this article to solve routing problems with multiple heterogeneous UAVs. The performance of GA is successfully evaluated based on different criteria, such as the variation in the number of UAVs, the number of consumers, and the number of iterations. Then, the information is stored in the blockchain to secure the delivery information. However, for simplicity, the complexity of the mathematical puzzle is intentionally kept low, resulting in minimal variation in TPS using the PoA consensus mechanism. The difficulty of PoW impacted the TPS in real-time scenarios, resulting in an overall decrease in TPS. In PoA, it is a predetermined duration, and the TPS remained constant and unmodified during the specified period. Therefore, a private blockchain network based on PoA demonstrated more stability for long-term establishment when compared to PoW for storing parcel delivery information in the blockchain network.

For the implementation of GA, the experiments can be repeated several times without modifying the algorithm in the future, including a large number of consumers and a large number of UAVs. Additionally, it is possible to extend iterations in order to achieve more favorable outcomes. Additionally, Real-Time Kinematic (RTK) technology can be included in the UAV in the future to enhance the performance of this proposed system.

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