AerialBlocks: Blockchain-Enabled UAV Virtualization for Industrial IoT

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***Abstract*—Unmanned Aerial Vehicles (UAV) are coming up as a powerful tool in various industrial applications in the context of enabling Industrial IoT. The limited power source and flight time of UAVs along with the need for skilled UAV operators are some of the most daunting challenges to the integration of UAVs in industrial applications such as site inspection, workforce monitoring, logistics, and others. In this paper, we propose the unique paradigm of AerialBlocks for blockchain-enabled UAV virtualization to provide virtual UAV-as-a-service for industrial applications. AerialBlocks also aims at providing secure and persistent UAV services to the end-users along with a partially decentralized blockchain model to ensure security, privacy, service quality, and transparency. UAV virtualization allows persistent UAV services, globally, without procuring any physical UAVs. The platform offers virtual UAV services on a pay-per-use basis to the end-user. The UAV owners and virtual UAV service providers gain monetary benefits for their contribution to the UAV services. Finally, we discuss the implications of the proposed platform on the domains of Industrial IoT and the possible challenges in the implementation of this paradigm.**

***Index Terms*—Industrial Internet of Things, Unmanned Aerial Vehicles, Virtualization, Blockchain, UAV-as-a-Service.**

I. Introduction

UNMANNED Aerial Vehicles (UAV) have seen a tremendous increase in its usage and market growth in the last decade. The global market of commercial UAVs is estimated to grow to 129.23 billion dollars by 2025 [1]. As a UAV is capable of small flights with payloads, traversing arduous terrains, and covering longer distances in a shorter time compared to its terrestrial counterparts, UAV has found its utility in almost every sector of the present industries, worldwide. The industries using UAVs range from agriculture, logistics, constructions to telecommunication and networking, security, and military. However, the resources of a UAV on-board is constrained and limited in nature. One of the major concerns is the limited power source of a UAV, which results in a shorter flight time of a UAV. The missions involving longer flight duration either do not complete or have to be completed using multiple UAVs to enable persistent UAV service. The existing solutions require multiple physical UAVs, dividing a long-duration UAV mission into sub-tasks, scheduling of UAVs. The solutions require UAVs to be manually controlled by skilled UAV pilots, with a line-of-sight mode of operation. To overcome all of the limitations of UAV operations mentioned earlier, we introduce the paradigm of secured UAV virtualization [2] to enable persistent and ubiquitous UAV services for industrial applications. We propose AerialBlocks that incorporates UAV virtualization through a common platform where UAV owners, end-users, and service providers can interact and share their common interests.

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A. UAVs in Industrial Applications

The present-day involvement of UAVs in industries is mostly indirect in the form of surveillance of machinery, tracking and information of the raw material in storage yards, and visual data of arduous remote areas. Industries such as mining and transportation use UAVs for aerial imagery and generating 3D maps of the target region. The UAV-based inspection of remote and hard-to-reach areas in potentially risky high-power transmission lines is also one of the rapidly upcoming and accepted replacements for manual inspection in electricity generation and distribution industries. We discuss two different scenarios with the application of AerialBlocks shown in Fig.1.

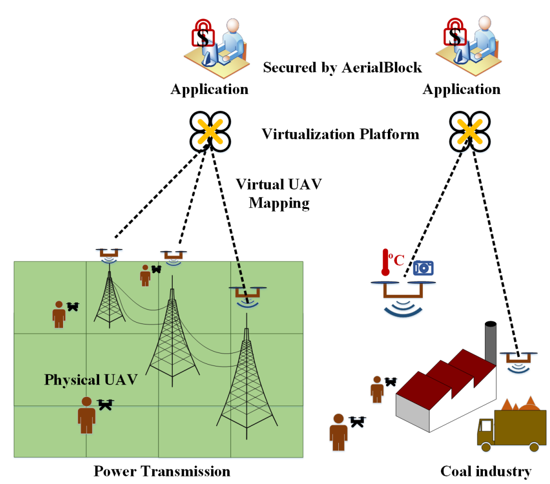

Fig. 1: The schematic mapping of physical and virtual UAVs in AerialBlocks.

1) Scenario-1: Let us consider the scenario of inspection of power transmission lines. Typically, long-distance transmission towers are tall and carry fatally high voltage supplies, which makes it significantly formidable to approach manually. With the introduction of AerialBlocks, the transmission lines can be monitored and inspected for faults such as partial discharges and hotspots. Virtualization allows different UAV

TABLE I: The advantages and shortcoming of UAV usage in industries.

Industry	Advantages	Disadvantages
Oil and Gases	Leakage inspection, continuous long distance aerial monitoring	Limited battery, require multiple UAVs at different distances
Steel	Machine inspection, inspection of regions with high temperatures	GPS location may not be available, high temperature endurance material of UAV frame and sensor
Civil construction	Structural inspection, raw material monitoring, work status updates	Limited battery, require multiple UAVs at different distances
Transportation	Tracking status, material moitoring	Limited battery, Require multiple UAVs at different distances
Mining	Aerial imagery, 3D mapping of mines	Limited battery, require multiple UAVs at different distances, GPS signals may not be available inside mines
Power distribution	Monitoring high power distribution lines	Limited battery, require multiple UAVs at different distances, possible electromagnetic interference
Agriculture	Crop health monitoring and aerial spray	Limited battery, require multiple UAVs at different distances, charging supply may not be available on fields

owners to rent their UAVs in the platform. These UAVs inspect the transmission lines spread over long distances. Additionally, other users may opt for the aerial images of the agricultural lands in the vicinity of these transmission lines. Hence, the same UAV serves multiple user applications. Implementing blockchain provides data security and privacy to the power transmission industry. Hence, AerialBlocks provides secured UAV services for the industry without having to acquire physical UAVs for different locations, separately.

2) Scenario-2 : The second scenario considers the coal industry. One of the major advantages of UAV is the inspection of large chimneys at the coal factories. These chimneys are large and have a very high temperature. Additionally, the UAVs can also monitor the raw material yards/ storage sites at the same time. However, the monitoring requires long flight time, which is not possible by a traditional UAV. AerialBlocks, bringing together virtualization and blockchain, provides continuous aerial monitoring for the factory site along with secured and privacy-protected data transmission.

UAVs are also finding common usage in the inspection of oil pipelines, dams, reservoirs, and other concrete structures for their structural integrity. UAVs with multiple sensors can be used to serve multiple purposes with a single aerial unit. One such example can be a UAV with a camera as well as a temperature sensor. It can be used to monitor an industrial site where visual inspection and temperature readings are necessary, such as monitoring a furnace or the periphery of a tall chimney. Table I discusses the utility of UAVs in various industries.

B. UAV Virtualization and UAV-as-a-Service

We propose a novel architecture to enable persistent and ubiquitous UAV services by implementing the concept of *Virtual UAVs* for continuous industrial tasks/ applications. The proposed architecture is similar to sensor virtualization [3], but is unique towards creating a platform to facilitate virtual UAV-as-a-service to the end-users. The end-users register to the platform to avail the UAV services, without procuring any physical UAVs. The proposed architecture consists of three actors – 1) UAV owner, 2) End-users, and 3) virtual UAV Service Providers (vUSP). Fig.2 shows the layer-wise interaction of components and actors in the proposed architecture. Here, a UAV owner registers his or her UAV in the platform to serve the UAV service requests by the end-users. The UAV owner earns monetary benefits from the platform for the missions completed by his or her UAVs. The UAV owner takes care of the maintenance of the UAV, such as charging of the batteries and sensor replacement. End-user registers to the platform to avail UAV services on a pay-per-use basis. The platform allows the end-user to get different types of on-demand UAV services without procuring and maintaining any physical UAVs. The vUSP is the connecting link between the UAV owners and the end-users. The vUSP provides the common platform and infrastructure to implement the virtualization of UAVs and providing virtual UAVs as a service to the end-user. Table II compares the existing traditional UAV models with the proposed virtualization model and AerialBlocks.

We divide the proposed architecture into three different layers – 1) Application layer, 2) Virtualization layer, and 3) Physical layer. The physical layer consists of the physical UAVs available on the ground for performing various UAV missions. The UAV owners register these UAVs with the platform provided by the vUSP. The UAVs connect to a remote server, which hosts the service platform, and send status messages to the remote server. The status message consists of the location information and the health status of the UAV, such as battery status, availability, active sensors, and other in-flight parameters. The UAV owners are associated with the maintenance of the UAVs in the physical layer.

The virtualization layer is the connecting layer between the

TABLE II: Comparison of the proposed AerialBlocks with existing traditional technologies.

Features	**Traditional UAVs**	**Traditional UAV Network**	**Virtual UAV**	**AerialBlocks**
Range of operation	Line of sight, short range	Line of sight, short range	Remote, global	Remote, global
Duration of service	Less than 30 minutes	Less than 30 minutes	Ranges in hours, depending on the available UAVs	Ranges in hours, depending on the available UAVs
UAV Ownership	End-user	End-user	UAV owner	UAV owner
Cost of service	Full procurement, service cost	Full procurement, service cost	Pay per use	Pay per use
Data security	No	No	No	Yes
Quality of service	No guarantee	No guarantee	No guarantee	Guaranteed

physical and application layer. It consists of the infrastructure required to implement the virtual UAV service platform by the vUSP. The virtualization layer establishes two-way communication with the physical UAVs, maintains and updates the database as per the current status. Similarly, the virtualization layer sends and receives end-users' data from the application layer. The virtualization layer can is equivalent to the brain of the proposed architecture. It analyzes and processes the data, and provisions virtual UAVs. The process of provisioning a virtual UAV includes mapping the physical UAVs to a virtual UAV in an application.

Finally, the application layer consists of the web-based applications that are created for the end-user and the UAV owners to get the services of the platform. An end-user application stores the request details such as location, type of sensor, time, and duration of the task. The UAV owner's application stores the necessary information of the UAV, such as type of sensor, date of procurement, type of battery, and dynamic information such as availability of UAV, current battery status, location, and assigned UAV service requests.

C. *Need for Blockchain in UAV Virtualization*

Our proposed architecture of UAV virtualization creates a business model that involves a transaction between the three actors – end-user, UAV owner, and the vUSP. The end-user and UAV owner avail the services from the platform provided by the vUSP. The platform services rely on a massive amount of data transfer between the physical UAVs, remote servers, and end-users. Thus, security is a major concern in the UAV virtualization architecture. Additionally, the business model created by UAV virtualization can create oligopoly market scenarios. With little to no significant competition among the UAV owners, the fairness in the price charged to the end-users for the vUAV services is likely to be compromised. Hence, we propose AerialBlocks– an implementation of blockchain in UAV virtualization to maintain the security, transparency, and fairness among the three actors and the platform. AerialBlocks incorporates the following features in the UAV Virtualization model:

- *Privacy and security:* In UAV virtualization architecture, multiple virtual UAVs from different applications are mapped to the same physical UAV based on the common interest. This mapping essentially means that the data from the same physical UAV is replicated and processed for multiple applications as per the requirement. Hence blockchain addresses the issue of data security and privacy while serving the end-users. Another aspect of privacy is to maintain secured transmission of control data between the platform and the physical UAVs. Blockchain ensures that the missions or tasks assigned to physical UAVs are not corrupted or altered by any malicious third party.
- *Improved service quality and user experience:* Virtualization architecture use a pay-per-use model for the end-user. The quality and quantity of data delivered to the end-user affect the cost of the services. Blockchain ensures validation of the user-level and service-level agreement and helps maintain fairness.
- *Blockchain implementation in UAV Virtualization architecture:* UAV virtualization architecture implements blockchain in the application layer and the physical layer with the virtualization layer in the middle, as shown in Fig.2. The blockchain is light-weight in nature and supports smart contracts and service agreements to incorporate all of the discussed features.

II. Related Works

The resource-constrained nature of UAV has led to many developments in recent studies. A commercially available UAV is estimated to fly for approximately a maximum of thirty minutes with a single charge cycle. Hence, persistent UAV service is a major concern for missions requiring long flight duration, such as industrial site monitoring and surveillance, logistics, land survey, and security presence. Erdelj *et al.* proposed an unmanned aerial system to provide persistent UAV-based structural inspection [4]. The authors simulated and implemented a scheduling algorithm to allow multiple UAVs to take on an inspection mission in parts. The authors controlled the UAVs through a ground control station using MAVlink commands and messages. Trotta *et al.* proposed the charging of swarm of small UAVs during the flight. The sequence of charging is decided and coordinated with the help of a bio-inspired algorithm [5] [6].

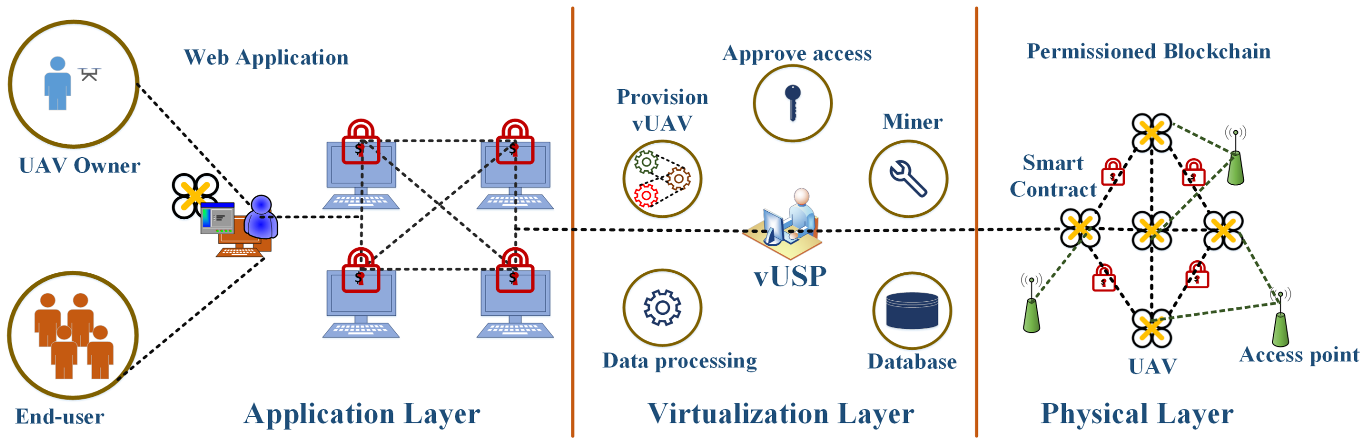

Fig. 2: The proposed AerialBlocks architecture with different layers.

The privacy and security of the data received from the UAV are of utmost importance. The security challenges associated with UAVs involve secure data transmission between the UAVs and the ground control station, control data transmission to guide the flight, UAV health parameters, and confidential sensor data [7]. Yoon *et al.* proposed the virtualization of sensors and actuators onboard a UAV to add resilience against a malicious override of UAV operations [8]. In case of detection of any suspicious activity, the system switches to a trustworthy mode of operation and prohibits any system overrides. He *et al.* proposed solutions to different communication security threats to UAV in [9]. The authors evaluated the attacks and spoofing in a communication channel between a UAV and a ground control station. Rashid *et al* proposed an Identity-based authentication scheme for heterogeneous networks of UAVs serving military purposes in [10].

Blockchain is known for its decentralized architecture and high security. Blockchain in IIoT helps achieve privacy, transparency, and security in the operating environment [11]. García *et al.* proposed a security mechanism for a network of UAVs operating for surveillance. The scheme utilizes blockchain-inspired peer-to-peer confirmation to validate the authenticity of a UAV in the network [12]. Abubaker *et al.* proposed a blockchain-based business model for hiring vehicles and implemented in Ethereum [13]. The architecture uses a proof-of-work consensus algorithm for validation. It enables the sharing of real-time traffic information to the users hiring the vehicle. Kuzmin *et al.* proposed a blockchain-based structure for a network of UAVs with a proof-of-graph consensus mechanism to ensure secured UAV flight operations [14].

A. Synthesis

The current state of the art holds for ideal conditions and does not have a platform to support the operations in real fields. The UAVs operate in a line-of-sight range, which is not always feasible in scenarios such as surveillance, land mapping, and logistics. Also, the energy-constrained power supply of UAV does not allow for long-duration flights. Scheduling of UAVs to perform long-duration tasks requires multiple physical UAVs to be lined-up for operation, which makes it economically taxing. Hence, there must be a solution in place to harness and fill this technological void. We propose AerialBlocks as a solution to the problems mentioned earlier.

III. AerialBlocks: Blockchain-enabled UAV Virtualization

The proposed blockchain-integrated UAV virtualization architecture achieves a higher degree of security, privacy, and transparency. The personal and confidential data entered by the end-user and the UAV owner is privacy protected and secured by the implementation of blockchain. Blockchain, through its complex cryptographic functions and hashing techniques, ensures that an outside entity does not alter the data entered by the actors in the platform. Data transmissions are recorded in the distributed ledger of the blockchain and serve as proof of the transaction. Additionally, blockchain creates transparency in the transactions taking place during the task and after task completion. The transparency, in turn, results in fairness in the business model in terms of the price charged for the tasks completion, and task assignment in terms of the UAV owners. The vUSP has to gain some percentage of profit from the platform, storage, and analytics provided to the end-user and UAV owner, which can be accommodated using a pricing model-based service distribution.

Fig. 3 shows the comparison of the transmission time for basic UAV health data through our implemented AerialBlocks and direct transmission without blockchain. We record the readings for a duration of 10 seconds each for a total of 20 flights. The transmission time in AerialBlocks is slightly higher than the direct transmission. It is due to the additional time required to send the data through blockchain transactions and create new blocks for the transmitted data.

A. Salient Features

- **Permissioned blockchain architecture:** We propose a permissioned blockchain model for our AerialBlocks architecture. The permissioned blockchain ensures that only the registered end-users and UAV owners can access and take part in the blockchain network in the platform to enhance the level of security and authority. The vUSP

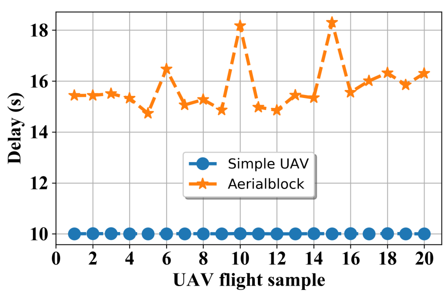

Fig. 3: Transmission delay incurred during data transmission in proposed AerialBlocks and direct data transmission.

acts as a miner and also has the authority to provide access to the platform users.

- **Resource sharing:** The virtual UAV provisioning at the virtualization layer is responsible for mapping the physical UAVs to the end-user applications. If the system receives similar requests in terms of the location and sensor type, the virtual UAV provisioning system assigns the same UAV resources to the applications, enabling resource sharing. The detailed information about the applications mapped to standard physical UAVs is kept abstract from the end-user to maintain privacy and security through the implementation of blockchain.
- **Smart contracts:** A smart contract is used to store the transactions and business regulations. For a UAV owner, the smart contract includes the agreement for service availability as per the specified information in the application. It contains the location of the mission, duration, type of data to be delivered, storage space assigned in the platform, and other such information. The service agreement for UAV owners has a different set of rules where the owners may specify minimum service time, UAV health certification, and agreement of UAV rent.
- **Security and Privacy:** The platform facilitates registration for both end-users and UAV owners. The registration process enables the application user to enter their details before using the services. The platform authenticates and validates the users each time before provisioning virtual UAVs to the applications. Similarly, for UAV owners, it validates the UAV status before assigning any service requests. The platform ensures secured access through the registration process and generates smart contracts for secured and quality services. UAV communication is generally radio or WiFi-based communication and prone to attacks and spoofing. Blockchain secures the data by securing the control and sensor data from the UAVs through authenticated and validated blocks.
- **Consensus Mechanism:** The proposed AerialBlocks consists of resource-constrained UAV nodes. We propose the use of Proof of Authentication (PoAh) [15] as the preferred consensus mechanism in our proposed AerialBlocks. The PoAh algorithm uses the ElGamal encryption method while signing a block before sending it for validation. Practical Byzantine Fault Tolerance (pBFT) is another consensus algorithm, which can manage faulty or malicious nodes. The algorithm ensures that the architecture functions correctly, even during node failures or suspicious node responses. We propose a combination of both PoAh and pBFT consensus algorithms to ensure light-weight validation with fault tolerance mechanisms. We outline some of the existing consensus algorithms in Table III.

IV. Implications

The effect of AerialBlocks on the existing IIoT applications is purported to be immense. Some of these are summarized as follows:

- The proposed UAV virtualization platform will enhance the utility of UAVs in IIoT as well as IoT implementations.
- UAV virtualization will enable the use of heterogeneous UAVs and sensor type as per the availability of UAVs in the platform rather than procuring fixed asset UAVs.
- Virtual UAVs will be suitable for long-duration industrial missions, without the need to employ additional workforce to take care of multiple physical UAVs and their scheduling mechanisms.
- Blockchain will ensure that the data received from the sensors arrive through secured transmission channels and maintain appropriate privacy.
- Blockchain will enable transparency to maintain the fairness in prices charged for the services so that neither of the actors associated with the architecture is exploited, and the market stays competitive.
- UAVs procured by the industries or individuals can be registered to the platform to gain monetary benefits when the UAV is in idle condition.
- The cost of UAV missions will be reduced as similar requests will be served with a minimum number of UAVs, rather than using the traditional method of one UAV for each task.

V. Challenges

The implementation of the proposed AerialBlocks requires to address some challenges associated with its underlying technologies and infrastructure. The following points have to be considered while implementing the proposed AerialBlocks platform:

- Technology for implementing UAV virtualization has to be explored. Network Function Virtualization (NFV) and Software-defined Networks are some of the technologies that can be considered for implementation and feasibility study of the proposed AerialBlocks.
- The virtual UAV services will depend on the availability of physical UAVs registered with the platform. UAVs have to be readily available for the flight missions.
- The backbone infrastructure will play a crucial role in implementing the proposed AerialBlocks. The physical UAV has to be connected to the Internet to transmit their data in real-time. UAV missions in network-agnostics

TABLE III: Comparisons of some of the basic consensus algorithms with their suitable application areas.

Algorithm	Highlights	Advantages	Disadvantages	Suitable Industry
Proof of Work	Selects next block miner, uses complex mathematical problem for an easy verification	Very complex to solve	Requires huge power and computation	IT, Stock Market
pBFT	Fault tolerance among nodes during consensus, uses default votes for the faulty or misbehaving nodes	Handles faulty nodes, energy efficient	Not suitable for large networks	Sensor networks, web-based services
Proof of Burn	Nodes burn coins that cannot be retrieved, nodes with higher number of coins burned gets to be the miner	No hardware or energy wastage	No utilization of the burned coins, unfair advantage to nodes with more coins	Mining, agriculture, power distribution and transmission
Proof of Stake	Nodes bet coins, higher bet gets to be the miner, incentive-based algorithm	No expensive resource utilization	Nodes with higher invested coins dominate as miners	Mining, agriculture, power distribution and transmission
Proof of Elapsed Time	Every node wait for a time period, after the time elapse, the node becomes the miner	Fair selection of miner, equal opportunity to all the nodes	Waiting time	Industry with mining, agriculture, power transmission
Proof of Capacity	Nodes share hard drive space, node with maximum space gets to be the miner	Energy efficient, no wastage of coins	Wastage of disk space	Oil and gas, electrical distribution, steel
Proof of Authentication	Nodes use ElGamal encryption scheme	Energy efficient, no wastage of resources	NA	IoT-based industry
Proof of Authority	Nodes use identity as trust	No wastage of resource	NA	Service industry

regions may face the unavailability of UAVs, delayed status updates of UAV health, and flight status.

- Existing UAVs are energy and resource-constrained in nature. Implementing blockchain will require powerful processing and computation capabilities at the UAVs as well as the vUSP platform, depending on the type of architecture.

VI. Future Prospects

- *Integration with 5G and beyond networks:* The current network scenarios include either a cellular network with 4G connectivity or WiFi-based connectivity. However, remote locations have to rely on cellular networks. The integration of the 5G communication network with the proposed AerialBlocks will not only increase the rate of connectivity but will also bring data security and improved quality of service. The use of this paradigm with future technologies such as Terahertz-band communication, which have typical data rates of a few Terabits per second, would be a significant boon for this proposed paradigm.
- *Artificial Intelligence and Machine Learning-based algorithms:* Intelligent algorithms with learning abilities can be used to automate the provisioning of virtual UAVs. UAVs can be trained to coordinate among themselves to achieve fully autonomous scheduling. The major challenge faced is to implement light-weight ML and AI algorithms onboard UAV to achieve accuracy and efficiency.
- *Satellite-based backbone network:* In the absence of cellular network or WiFi connectivity, satellite networks can be harnessed to provide interim communications to the UAVs. Also, with an increasing number of UAVs, the interference is bound to increase. Satellite to UAV communication is still a majorly unexplored domain and can be explored for more robust communication channels. The UAVs may also serve as aerial earth stations for the LEO-based satellite constellations for enabling the space-based global Internet.

- *Integration of Augmented Reality (AR) and Virtual Reality (VR):* Visual feed from UAVs have been used in many application scenarios. Integration of AR and VR with UAVs can significantly enhance the user experience and efficiency of the UAV applications such as survey, monitoring and inspections of industrial sites, public areas and other regions of interest.

VII. Conclusion

In this paper, we proposed a novel scheme, AerialBlocks, for blockchain-enabled UAV virtualization in industrial IoT environments. AerialBlocks ensures a promising enhancement of services as compared to traditional approaches, and offers faster and robust retrofitting of traditional industrial tasks with industrial IoT. The UAV virtualization paradigm enables persistent UAV services for long-duration missions without procuring physical UAVs. A web-based application is used by the end-users and the UAV owners to avail of the services. The integration of blockchain to this paradigm adds a higher level of security, privacy, and transparency in the platform and its services. We further discuss various blockchain algorithms and their possible usage scenarios in line with the proposed paradigm. Finally, we outline the major implications of such a paradigm, the challenges, and the future prospects of this paradigm in industrial IoT environments.

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