Blockchain for Internet of Drones: Applications, Challenges and Future Directions

Maninder Pal Singh, *Student Member, IEEE,* Gagangeet Singh Aujla, *Senior Member, IEEE,*
Rasmeet Singh Bali

Abstract—Drones or unmanned aerial vehicles (UAV), started as a byproduct of military research are passing through its most popular period when they are being used in broader horizons, and more possibilities are being explored in commercial applications. The evolution of drones is quiet interesting and this article provides some of the key chronology of different time quanta related to the emergence of drones in global market. During this journey, the size-shape-form of drones has also evolved, thus different drone topologies are also discussed here. We have also considered the wide range of drone applications (every nook and cranny) for a comprehensive discussion. Hereon, this article discusses the emergence of *Internet of Drones* and its industrial application perspective. Now, the advancement brings key concerns, and the security has always been a concern for these manless machines. Thus, we highlight the key security concerns and then propose the trending Blockchain as a key solution for these concerns. However, blockchain-drone coalesce has always witnessed key concerns from the research community. We discuss these concerns and alongside we present some derived blockchain architectures that tend to resolve these concerns. The later part of this article presents a case study for drone-based community delivery in pandemic-like situations using a derived blockchain architecture. The article concludes with the key open issues and future challenges.

Index Terms—Blockchain, Drone delivery, Derived Blockchain, Drone topology, Security, Internet of Drones, Industry 4.0.

1 Introduction

Drones, also known as unmanned aerial vehicles (UAV) are airborne vehicles that can fly without the pilot on board. This idea of manless flying objects is a byproduct of military research aimed at reducing the risk involved in carrying out operations. Although the usage of drones is traced back to World War 1, in current times drones have crossed broader horizons, and more possibilities are being explored. This proliferation can be attributed to the integration of technologies like, cloud computing, artificial intelligence, and advanced sensing mechanisms. Another contributing factor is that drones are becoming inexpensive and more accessible making them a good fit in numerous areas like aerial photography, logistics, geographical mapping, disaster management, precision agriculture, search and rescue, weather forecast, and wildlife monitoring being a few of many. The widespread applications led to the development of different types of drones depending upon factors like their size, weight, payload capacity, and flight range.

The drone can primarily be operated in two ways based on their pilot systems which can be fully autonomous and remote-controlled. The drones are being built in such a way that they are becoming smaller yet powerful, not just in the sense of payload-carrying, but also in their flight capabilities. As remote controlling of drones has the dependency on ground control stations for the drone actions, it has brought in certain limitations like communication links are prone to failures, unplanned hindrances during the flight are to be reacted upon through the ground remote controlling and most importantly, human intervention is required. This has led to the new generation of drones that can make use of computer vision algorithms combined with decision-making mechanisms resulting in autonomous flights.

1.1 Evolution and History of Drones

In Fig. 1, a chronological evolution of drones [1] is presented by segregating it into three time quanta discussed below:

1.1.1 Early Era

The use of drones began in 1917 when they were used as flying bombs in World War 1. Thereafter, the Military of different countries kept investing in research on UAV technology, and as a result the World War 2 witnessed the use of remote controlled drones. Thereon the drones research moved towards surveillance during cold war [1].

1.1.2 Military Era

By 1973, the use of the drone for surveillance by the military became popular and by the year 1985 huge investments were made to scale up the UAV development, which resulted in GNAT 750 and thereafter bigger and sturdier Predator drone. The US army used Predator extensively in the Afghanistan war and subsequently drones were used in Pakistan, Yemen, and Somalia [1].

1.1.3 Commercial Era

Until the year 2006, drones were not legalized for non-military purposes. As the federal aviation administration (FAA) lifted certain limitations, camera-equipped and remote-controlled drones were available in the commercial

- *M Singh and R S Bali is with the Department of Computer Science and Engineering, Chandigarh University, India.*
- *GS Aujla is with the Department of Computer Science, Durham University, Durham, DH1 3LE, UK. E-mail: gagangeet.s.aujla@durham.ac.uk*

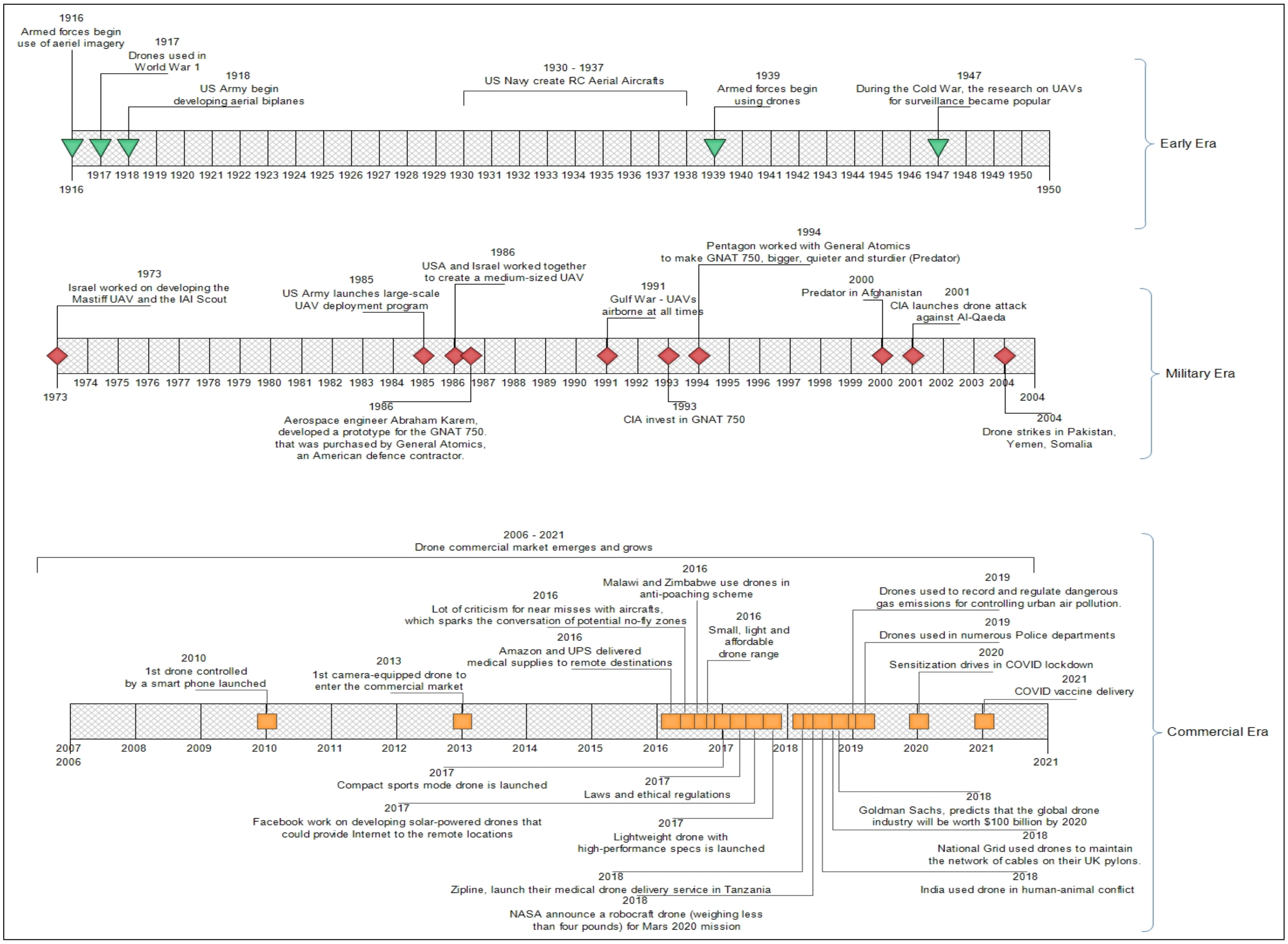
1916
Armed forces begin use of aeriel imagery
1917
Drones used in World War 1
1918
US Army begin developing aerial biplanes
1930 - 1937
US Navy create RC Aerial Aircrafts
1939
Armed forces begin using drones
1947
During the Cold War, the research on UAVs for surveillance became popular
1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950
Early Era
1973
Israel worked on developing the Mastiff UAV and the IAI Scout
1985
US Army launches large-scale UAV deployment program
1986
USA and Israel worked together to create a medium-sized UAV
1991
Gulf War - UAVs airborne at all times
1994
Pentagon worked with General Atomics to make GNAT 750, bigger, quieter and sturdier (Predator)
2000
Predator in Afghanistan
2001
CIA launches drone attack against Al-Qaeda
1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
1986
Aerospace engineer Abraham Karem, developed a prototype for the GNAT 750. that was purchased by General Atomics, an American defence contractor.
1993
CIA invest in GNAT 750
2004
Drone strikes in Pakistan, Yemen, Somalia
Military Era
2006 - 2021
Drone commercial market emerges and grows
2010
1st drone controlled by a smart phone launched
2013
1st camera-equipped drone to enter the commercial market
2016
Amazon and UPS delivered medical supplies to remote destinations
2016
Lot of criticism for near misses with aircrafts, which sparks the conversation of potential no-fly zones
2016
Malawi and Zimbabwe use drones in anti-poaching scheme
2016
Small, light and affordable drone range
2019
Drones used to record and regulate dangerous gas emissions for controlling urban air pollution.
2019
Drones used in numerous Police departments
2020
Sensitization drives in COVID lockdown
2021
COVID vaccine delivery
2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
2017
Compact sports mode drone is launched
2017
Laws and ethical regulations
2017
Facebook work on developing solar-powered drones that could provide Internet to the remote locations
2017
Lightweight drone with high-performance specs is launched
2018
Zipline, launch their medical drone delivery service in Tanzania
2018
NASA announce a robocraft drone (weighing less than four pounds) for Mars 2020 mission
2018
Goldman Sachs, predicts that the global drone industry will be worth $100 billion by 2020
2018
National Grid used drones to maintain the network of cables on their UK pylons.
2018
India used drone in human-animal conflict
Commercial Era

Fig. 1: Chronological evolution of drones [1]

market by 2013. Ever since drones became small, light, and affordable, they started to appear in various commercial applications. In 2016, the drones were deployed by amazon and UPS for delivering items. Subsequently, in 2018, the drones were used by Zipline to deliver medical services in Tanzania. During these times, NASA announced that drones will be used on their 2020 Mars mission. This worked as a catalyst in drone development and in 2018 Goldman Sachs predicted that the drones market will be around $100 billion by 2020. COVID-19 also witnessed the use of the drone for sensitization drives and vaccine delivery in 2020-21 [1].

1.2 Drone Topology

Drones are available in various shapes and sizes and even some forms are so similar to the conventional forms (as shown in Fig. 2) that it becomes difficult to differentiate, a brief elaboration [2] of different forms is as follows:

1.2.1 RC Helicopter

The RC helicopters are comparably challenging to fly than quadcopters as very few onboard software controls are available and as a result of one main motor-based architecture, it's less stable than a quadcopter drone.

1.2.2 Coaxial Helicopter

The structure of its motor shaft is built in concentric coaxial form with one shaft rotating one rotor in clockwise (CW) direction and the second shaft rotates the other rotor in the counter-clockwise (CCW) direction. The electric coaxial helicopters are stable and easier to fly than a conventional helicopter.

1.2.3 Tricopter (Y)

It uses three motors to generate buoyancy in an equally distributed motor layout with the usually 120-degree angle between the arms. Tricopters have special YAW servo motors that can tilt and hence counter the rotational forces. Subjected to the same motor power and blade sizes they are outperformed in terms of thrust offered by quadcopters.

1.2.4 Quadcopter (X)

It has become a de facto in the drone industry due to its stability, good upthrust, and easy maneuverability for small to mid-sized drones. The rotors are places at an even distance of 90 degrees in an X configuration, the four rotors work in two sets with each set having two rotors. One set of rotors have CW propellers and the other set has CCW propellers.

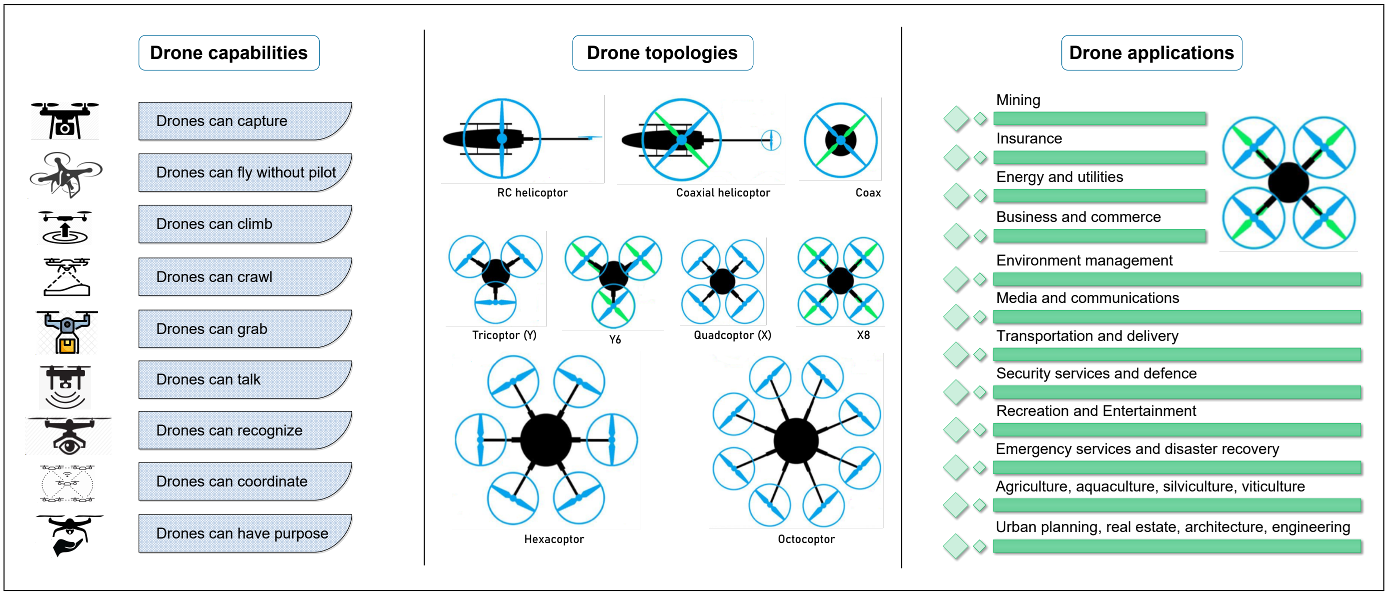

Fig. 2: Drone capabilities, topology and applications

1.2.5 *Hexacopter*

It has 6 rotors lead in the layout of two sets of three rotors each. The rotors in one set use CW propellers whereas the second set of rotors are in CCW configuration. Around the trunk, one CW rotor is followed by one CCW and so on resulting in an increased sized drone. But, more uplifting thrust is good for cargo delivery. Also, in case of a motor failure, the hexadrones do not crash and continue to fly.

1.2.6 *Y6 copter*

It is a combination of coaxial and Y3 copters as there are three arms with each arm having two rotors. Rotors on each arm work in CW and CCW manner thus elimination the servo motor needed by the Y3 copter for YAW.

1.2.7 *Octocopter*

It has eight arms at the same level with rotors configuration of consecutive rotors in CW and CCW fashion thus resulting in great uplift thrust and big size.

1.2.8 *X8 copter*

It is the drone layout with quadcopters and coaxial copters. Four equally distant arms have two rotors each and the rotor on one arm work in CW and CCW fashion. The resulting drone is more stable, has greater uplift, fault tolerance in motors and yet the size is lesser than the octocopter.

Although, there is no specific topology to be considered as best but among the various layouts, quadcopters layout finds their way into the most production drones for civilian usage. This is because of the maneuverability and stable flight dynamics in quadcoptors. However, the preference may change as per requirements and application scenario.

1.3 Applications of Drones

Drones have been deployed in several applications as shown in Fig. 2. Some of these application areas are discussed below [3].

1.3.1 *Emergency Services and Disaster Recovery*

Drones can be deployed in emergency services and disaster recoveries and help to save human lives. For example, drones can be used to deliver organs from remote locations and help to save time, as after the death the organs must be transplanted into the receiver body within a given time [4]. Likewise, for critical surgeries, drones can be used to deliver blood and medicine to remote areas and disaster/accident sites. Drones can play a vital role in critical disaster situations like avalanche rescue, and earth quack rescue. In forest fire or nuclear radiation-like situations, a drone can be used to assess the impact/scale of fire or radiation. They can assist the rescue teams in terms of communication capabilities for coordination and service relaying.

1.3.2 *Security and Law Enforcement*

Drones have huge potential for applications in the field of security services and law enforcement, for instance, drones can be used to investigate accidents. Similarly, drones can assist in air traffic management by providing real-time statistics and deter bird strikes on airplanes. Likewise for law enforcement drones are used for patrolling borders and detection of intruders, monitoring civil unrest, securing events being organized in open spaces like stadiums, access situation during terrorist attacks, and ensuring security and tracking of stolen vehicles. Thinking further, drones can help to get a clear picture of a crime scene, can be used to detect criminals using face recognition, and tackle the manic of human trafficking.

1.3.3 *Agriculture, Aquaculture, Silviculture, and Viticulture*

Drones can be effective in monitoring the crop against theft, the monitoring & control of harvest, crop dusting, pesticide spraying, and fertilizer management. In dairy farming, drones can be used for herd inventory & tracking by giving more accurate insights. Drone infrared (IR) sensors can be used for IR-based hydrology analysis for the prediction of the water system model of an area. Similarly, the IR vision-enabled drones can be employed to study plant communities for species composition and structure referred to as vegetation analysis. Further, irrigation monitoring using drones can be vital in optimizing water usage. In aquaculture, a drone can be effective in the detection of fishing schools and monitor school activities. In silviculture, drones can be used in controlled burning which is a mechanism that triggers the germination of trees in forests along with soil revealing thus escalating seedling and forest renewal. In viticulture, drones are useful in monitoring the growth of grapes harvest in vineyards along with winery management.

1.3.4 Urban Planning, Architecture & Engineering

The use of drones in the urban planning process and subsequent monitoring for the plan execution through realistic analytics of actual implementation can help to tackle future problems of parking, road congestion, and waterlogging. Similarly, in real estate development, key jobs like 3D imaging of structures, management, and monitoring of construction, highway design & monitoring pavement assessment, and site analysis can be benefited through drone deployment. Similarly, drones can be used in several inspection domains like the site, traffic flow, transportation, etc.

1.3.5 Media and Communications

Aerial photography is being used beyond hobbies, news reporting using drones, investigative journalism are very popular areas as well. Apart from media, drones are being used in the communications field as well, for on-demand cellular networks for catering to dynamic demands, FM repeaters, telecommunications, ultra-high-frequency radio, and even WiFi LAN. Drones act as parcel copters thus saving time and are more cost-effective.

1.3.6 Business and Commerce

Businesses industry is relying on drones to improve their services and expand their functionality. In real estate, the use of drones for videography and photography has triggered marketing and sales by providing a clearer top view to the buyers. Moreover, the sky scrappers and other buildings require window washing and painting that is too risky and also expensive, so drones can be used as an alternative. In the commerce field, stock measurement and tracking is an area is largely benefited from drones.

1.3.7 Recreation and Entertainment

Drones are used for recreational purposes like explorers use drones for videography to explore what's unseen on the planet. Likewise, drone-based aerobatics and drone boarding are gaining popularity. Drones can be used as party music equipment for surround effects in an open area or they can be used for wildlife viewing. Virtual reality-based drone flying is another trend for entertainment.

1.3.8 Transportation and Delivery

Drones act as small copters delivering parcels and many companies are investing in drones that can be used to deliver cargo across cities and even further. Parcel delivery using drones has many successful implementations like amazon prime air, flytrex, UPS flight forward, wingcopter, zipline, and DHL parcelcopter.

1.3.9 Insurance

The insurance industry is using drones to very assess the situation for claim settlement through better wider insights of events like road accidents, airplane crash sites, and fire damage assessment. thus, they can save money on false claims or claims arising of intentional damage.

2 Internet of Drones

The multi-varied autonomous flight capabilities of drones (as shown in Fig. 2) are expected to result in a substantial number of drones flying around in different form factors performing different jobs. The scalability and sustainability of a gigantic count of drones require a well-defined ecosystem for their coexistence with the ongoing airspace for airplanes being controlled by organizations like FAA. Thus, the Internet of Drones (IoD) emerged as a promising domain.

2.1 Architecture

IoD has to deal with multifaceted problems like drone routing, mutual coordination, diverse connectivity, environmental factors, and security concerns at hand. As suggested in [5] the architecture needs to be modular to be flexible and scalable for which layered model is a suitable candidate. Further, as the operation area for IoD is shared with existing regulated airspace, the movement of drones requires to be planned in different ways according to areas. As suggested, the area that is common with civil aviation airspace needs to be managed in a fixed flight route plan manner regarded as airways. In the places where free flights can be planned, the drones need to navigate on their own based on the surroundings that are regarded as nodes. The operational area is divided into zones and drones move among zones through fixed points known as gateways with each zone being administered by ground stations as shown in Fig. 3.

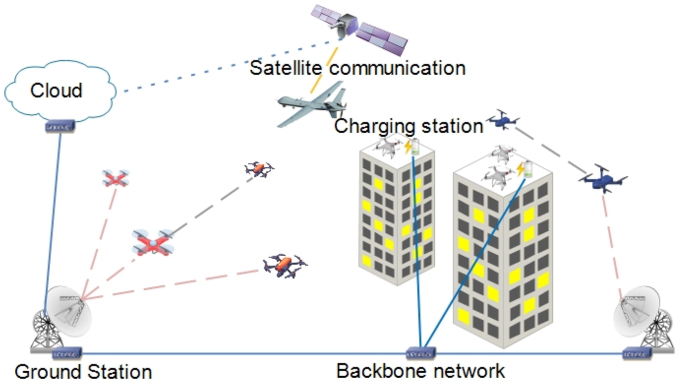

Fig. 3: Internet of Drones

2.2 Applications

Due to scalability and autonomy, IoD is popular in applications discussed below:

- **Drone Swarms** include several drones flying together to achieve a common goal like surveying. When a large number of drones fly together, manual control of flight is not feasible, hence autonomous operations is a viable option.

- **Logistics** is the field where drones are seen as a game-changer because of their reach, low operational cost, and faster delivery. Companies like Amazon, UPS are keen on drone-based delivery, which needs a completely autonomous system to perform the jobs.
- **Service Relaying** through drones is another area where massive investments are being made. Facebook's ambitious project to use a solar-powered drone to provide Internet services to remote locations is a step in this direction. If the model has to progress, it has to evolve into IoD for sustainability.

2.3 Industrial Perspective

Industry 4.0 makes the machines smart and enables synchronization of processes to the maximum which has a very basic requirement, data gathering, processing, and real-time tracking. IoD can be an enabler for this in areas where fixed infrastructure is not available for data collection and relaying, hence drones can act as service enablers. So to enable the use of drones they need to be monitored and managed, which is done through the IoD framework. In industries like *building construction*, the drones are used for thermal imaging and point-of-view surveys from different aspects that are hard to monitor [6]. *Oil and gas industry* is another field where drones are being used to help the inspection and maintenance operations which otherwise requires to halt operations and then humans visit the critical areas so that problems can be detected early and catastrophes can be avoided. Further, *mining industry* is taking benefits from drones for ensuring the stocks pile volume calculations thus efficient channelization of resources. Similarly, *sea port and shipping industry* is also utilizing drones for efficient operations by performing operation oversight, aerial situational, and traffic monitoring [7]. With IoD, the industrial processes can be automated and the continuously gathered data can help avoid mistakes that are overly expensive to rectify later.

2.4 Security Challenges

IoD is a broad field with a huge surface area, credited to the usage of heterogeneous underlying technologies for communications, computations, and data processing. The wide attack surface of IoD makes it prone to security and privacy challenges. Some of the key security challenges for IoD are discussed below:

Privacy: Drone carry sensitive information relating to the people involved, like in case of delivery, the drones have information of the customer (like name, contact details, payment details) which need to be safeguarded if a drone is compromised by an attacker to access to the information which otherwise is deemed to be kept private.

Data Integrity: Drones collect and store data onboard, which is exchanged with fixed infrastructure units (like ground stations) from time to time. If drones a compromised, it can lead to altering and manipulation of original data, which ideally is countered using cryptographic mechanisms that are usually too heavy for drones to handle. Hence, in the absence of suitable data integrity check the environment is susceptible to data manipulation.

Access Control: Some applications of drones require drones to mutually collaborate to gather information, e.g., geographical detailed mapping, this information can be dangerous if somewhere gets hands onto it for negative reasons. Hence, only verified authorized access controlling must be designed for the IoD.

Data Confidentiality: Drones in some applications like surveillance carry sensitive data like videos which it needs to transmit to other entities like ground stations and cloud. During transmission of data, it must be understandable to only the concerned entities, not to others listening to the medium, else confidentiality will be lost. Hence, mechanisms like encryption are required, but encryption has its limitation of exhausting the resources of both sender and receiver and especially when the data to encrypt and decrypt is large in volumes.

Control Site manipulation and single point of failure: In the traditional central architecture a central controller performs the responsibilities of various drones activities like registration, planning flights, routing, etc. At any moment if the central entity goes down due to either genuine reasons (like hardware faults) or intentional purposes (like security attacks), IoD will suffer from this thus creating the single point of failure which is not advised to deploy big systems.

3 Blockchain for Internet of Drones

The cryptographic methods can be used to secure the D2X communication in the IoD environment, but as the drones are equipped with limited resources, heavy cryptographic solutions are not appropriate. However, the principle of the *blockchain* could help to design a suitable security mechanism for IoD. Blockchain is decentralized in nature, data once recorded into a block is immutable and the independence from third-party dependency is the very big advantages of blockchain. It can be favorable to IoD by ensuring the decentralization of the ecosystem and yet ensuring the security of involved entities.

The concept of blockchain is just like a linked list that is secured through the linking nodes using the cryptographic hash functions. The fundamental element of the blockchain is the block which has two segments, header, and data. The various elements of block header and data part as defined by the IEEE standard for data format for blockchain systems [8] are discussed as below:

- **Block height** is the location of a block in the blockchain concerning the beginning. Hence, it gives the length of the blockchain up to the current block.
- **Block ID** is the unique identifier used to identify each block in the blockchain.
- **Block version** denotes the protocol versioning information in the blockchain that was used while generating a specific block.
- **Previous block hash** is the cryptographic hash link to the previous block. While a new block is generated the hash of its predecessor block is embedded into it which ensures the immutability of the blockchain.
- **Merkle tree root** is used to ensure the integrity of data by computing hashes of individual transactions and then stacking the hashes together to generate a

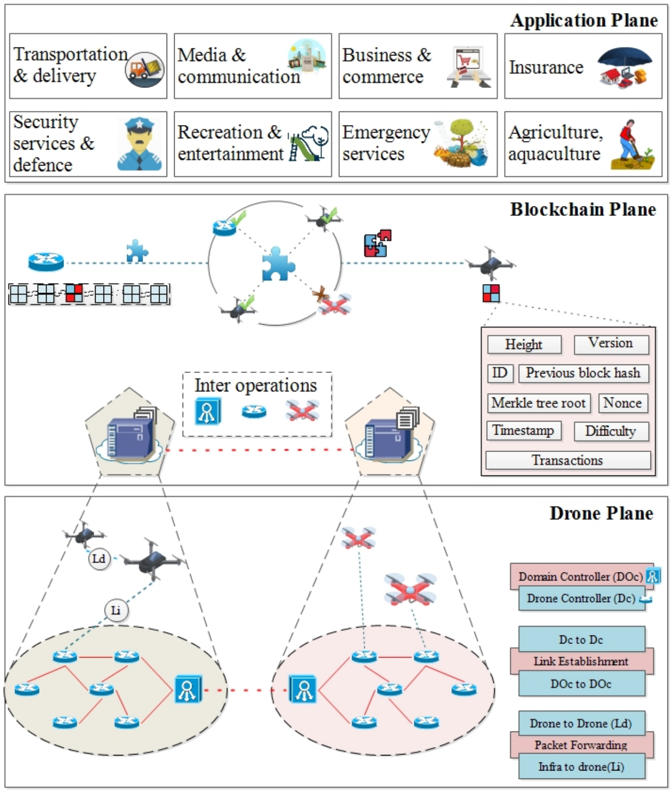

Fig. 4: Blockchain for Internet of Drones

final hash which is a superset hash of all transaction's hashes in the block.

- **Block timestamp** ensures the chronology of block generation. The moment a block is generated the timestamp indicator of the time instance.
- **Block nonce** is a pseudo-random number used to compute the target hash as per the set difficulty in the proof of work algorithm.
- **Difficulty** means the number of leading zero bits that must be zero in the target hash value as part of the proof of work algorithm.
- **Transaction list** include transactions recorded in a particular header. The size of the transaction is variable and blocks can have a different number of transactions. They make up the data of the header.

The data is added to the blockchain after validation of the transaction using a consensus mechanism that keeps the blockchain network consistent. Several mechanisms for consensus include proof of work, proof of stake, proof of space, and voting-based consensus. The architecture for blockchain-drone coalesce is shown in Fig. 4.

3.1 Key Challenges for Drone-Blockchain Coalesce

The blockchain ensures the data immutability by including the hash of the very predecessor into a successor thus building an almost perfect distributed system for transaction processing and management. But to ensure scalability, some challenges those needs to be addressed [14] are as follows:

3.1.1 Rapidly expanding storage requirement

The blockchain architecture requires all the blocks from the beginning for tracking a transaction. The increasing number of transactions on the blockchain is making it bigger in size [15]. The current growth rate of the bitcoin blockchain is 1 MB per hour, and if the blockchain scales up to the rate of transaction processing performed by companies like visa, the rate of size increment is expected to go up to gigabytes which is a challenge for resource-constrained systems. Further, the transfer of this big amount of data across the network is another challenge.

3.1.2 Power consumption

Like the most popular blockchain cryptocurrency bitcoin, some very complex algorithm runs at the core of the blockchain, like proof of work consensus algorithm. The cumulative power consumption of alone bitcoin network is gigantic. This elevated power demand is contributing to an increased carbon footprint.

3.1.3 Constrained throughput

Blockchain uses cryptographic functions to ensure the integrity of data along with consensus mechanisms requiring participation from multiple entities which limits the transaction processing rate of the blockchain.

3.1.4 Trade off between transparency and privacy

Although blockchain preserves the privacy of users through the usage of pseudo-random identities, still the transaction's data is visible to all participants. The traditional encryption methods on transactions are non-viable as other nodes can't understand the previous transactions and hence mining can't work. This brings a challenge to balance between transparency and privacy as per the application need.

3.1.5 Unfair Mining

Mining is the foundation of blockchain and if the miners aren't fair, it can lead to multiple conflicts, for instance, the miner does not publish the mined blocks and keeps on adding the blocks so that the chain with the miner grows larger than the other chains, in that case, the miner's chain is going to be considered valid and other legitimate blocks might get invalidated.

3.1.6 Governance challenges

Blockchain is decentralized, immutable, anonymous, and supported with automation through smart contracts, which is good from the security perspective. But, in the absence of proper regulations, regulating bodies, and planned access control, it becomes a choice for unfair activities and, poses a huge challenge for the adaptation of blockchain.

3.2 Unconventional Blockchain Architecture

Influenced from the challenges in conventional blockchain researchers have proposed different derivatives for blockchain. Just like the field of IoD, the application of conventional blockchain introduces a big problem as some of the nodes are drones that are already restricted in terms of resources, further the communication among drones and

TABLE 1: Comparison of unconventional blockchain architectures

Proposal	Architecture	Application	Contributions
Malik *et al.* [9]	Side chain	Food supply chain	Regulations, transaction throughput
Michelin *et al.* [10]	Decoupled blockchain	Smart vehicles	Data storage, transaction throughput, privacy
Lunardi *et al.* [11]	Appendable-block blockchain	Internet of things	Data storage, suitable consensus, transaction throughput
Aujla *et al.* [12]	Decoupled blockchain	Edge-envisioned IoT-based healthcare	Data storage, data compression, privacy
Singh *et al.* [13]	One drone one block	Internet of drones	Data storage, data compression, privacy, transaction throughput

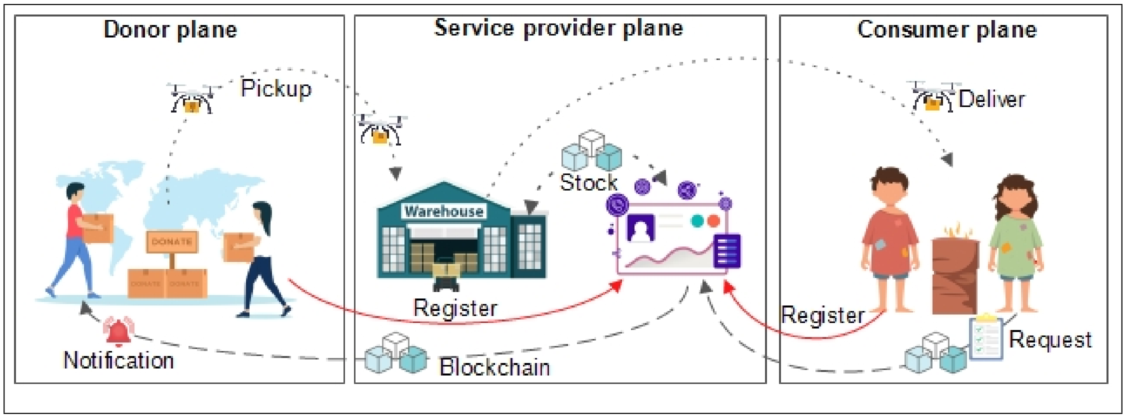

Fig. 5: Case Study for Community Delivery in Pandemic-like Situations

from drone to infrastructure happens through the wireless channels those have lesser throughput that wired networks. Authors in [9] have presented a blockchain architecture for food supply management in which a sharded has been proposed which works in a three-tier architecture. The authors have ensured the data is available to consumers yet maintaining confidentiality from competitors and transaction vocabulary along with transaction rights management has been illustrated in the model. In another work in [10], authors presented a decoupled data blockchain for the intelligent transportation systems arguing the need of decoupling the data to enable a faster and lighter blockchain mechanism for resource-constrained ecosystems. The decoupled data blockchain is an approach where the data is not stored on the chain and only the metadata is stored on the chain. The researchers have presented the idea of expiring keys to ensure the identity of the parties is kept intact. Further work was done in a similar direction in [11] where researchers analyzed the requirement suitable consensus mechanism for the decoupled and append-able block-based blockchain solutions. Researchers proposed a modular blockchain design for improved performance of the various consensus mechanisms and further evaluations indicated that the approach is effective as the new transaction addition time is around 7ms. The concept has been adapted for the IoD environment in [13] where the authors recommended using decoupled data blockchain for IoD along with a miner selection algorithm for performing voting-based consensus.

For the IoD ecosystem (derived from the drone-blockchain challenges), an alternative blockchain architecture can be more effective because of its lightweight nature, facilitating faster transactions and demanding lower energy for consensus protocols. Motivate from these facts, the proposed model is customized to cater to the special needs of the challenging and resource-constrained IoD environment.

4 Case Study: Community Delivery in Pandemic-like Situations

During COVID-19 pandemic lockdown, the physical delivery of goods via human involvement became tough, and hence the possibility of using drones to pick material from donors and deliver it to the consumer is considered in this work. Further, the use of derived blockchain is recommended to keep the system workable on lightweight machines based on [12] and [13].

4.1 Architecture

The proposed architecture as shown in Fig. 5 is segregated into three planes discussed as follows:

4.1.1 Donor Plane

The donor plane comprises of potential donors (D) that register via a registration process (D_{reg}) to get an unique identity (D_i). After registration, D_i get notifications of consumer requirements (R_n^{itm}) in different item categories (itm). If D_i wants to donate, a flag ($F(R_n^{itm})$) is raised for donation of itm, along with quantity (R_n) , for which a token ($T_{R_n}^{D_i}(itm)$) is generated called donation transaction token and is inserted into the blockchain transaction list (B_C^d). Further, drone (Dr_i) is scheduled to pick the itm from the D_i and brings into warehouse (Wh).

4.1.2 Service provider plane

This plane has the service provider interface (S_p^{int}) and management functionality along with operational unit of Wh. The itm picked from D are placed in Wh and the stock (S_{itm}) is updated via B_C transaction which include $T^{D_i}_{R_n}(itm)$ for a specific itm, this enables the transparent donation and stock management process. If a request is received C, the S_{itm} platform checks the availability in S_{itm}. If the current S_{itm} satisfies the requirement, it is delivered to the i C's location (C^{loc}_i) via Dr. In case of unavailability, a R^{itm}_n is sent to the group of D. The B_C is specially adapted as a unique block (b_{C_i}) is assigned for each itm, and the same b_{C_i} is amended over the time with newer updates.

4.1.3 Consumer plane

represents the needy who seek the goods provided by the donors. To get goods a consumer (C) is registers on a B_C and is assigned an unique identity C_i. Simultaneously in the derived B_C an block for that consumer (b_{C_i}). When needed the C_i submit a request R_i for items (itm) on the S^{int}_p platform. Each consumer is assigned a unique id (C_i) through B_C and a b_{C_i} is created for them. To preserve the privacy of C_i, pseudo random identities ($r(C_i)$) are allocated. After the delivery of itm to C_i via Dr, the corresponding b_{C_i} is updated. This ensures a fair and balanced distribution process.

4.2 Validation

The proposed case study has been evaluated through a Gazebo simulator along with an ardupilot and robotic operating system to simulate a drone swarm in a city scenario to mimic drone delivery. The parameter passing and data fetching have been routed through blockchain. The architecture was validated for the block generation time concerning the number of drones. The time depicted a linear growth with an increase in the number of drones. This suggests that the derived blockchain mechanism is suitable to the IoD ecosystem due to its throughput and less load.

5 Future Challenges and Directions

Based on the previous discussions, certain key areas that need attention in future research are discussed below.

- **Air space coordination:** Drones use the air space that is already used by airplanes/helicopters. So, there must be strict coordination regulations to ensure safe operations. Moreover, no drone should be allowed to enter the air space without verification.
- **Efficient scheduling:** IoD requires drones to fly in a synchronized manner to avoid any conflicts among drones or other entities Thus, efficient drone scheduling becomes a key challenge.
- **Location tracking**: The primary way to find the exact location of drones is GPS signals. But the accuracy of GPS is not precise according to the IoD needs. To tackle this, onboard computer vision-based decision making is another possibility but this can lead to additional computational load. Hence, a cost-effective method to track the drone movement with greater accuracy and less error is a future challenge.
- **Optimal resource allocation:** Drones are equipped with limited resources (like compute and battery). So, optimal resource management is always an open issue in IoD.
- **Appropriate QoS**: IoD works over the wireless networks that own inherited limitations and reliability issues. So, meeting the QoS requirements of delay-sensitive applications is another challenge for the future.
- **Big Data:** Drones are deployed for surveillance and tend to generate a huge amount of data. The transmission, storage, and processing of this big data in real-time is a key question.
- **Privacy Invasion:** Drones can be used for spying which is a big threat to privacy, and thus creating an anti-drone ideology. Thus, it is essential to design credible and trustworthy frameworks for IoD to gain people's confidence.

Acknowledgement

This work is partially supported by the Startup Fund from Durham university, UK (090614).

References

[1] "A history of drones: From then until now," Feb 2019. [Online]. Available: https://www.thecasefarm.co.uk/drone-cases__trashed/a-history-of-drones/

[2] O. Liang and K. Martinezkennedy@dronethusiast.com, "Y6 copter, y3 copter other multicopter configurations [2019]," Jan 2019. [Online]. Available: https://www.dronethusiast.com/what-you-should-know-about-multicopter-configurations/

[3] "Drone uses." [Online]. Available: https://droneuses.net/

[4] A. Konert, J. Smereka, and L. Szarpak, "The use of drones in emergency medicine: Practical and legal aspects," *Emergency Medicine International*, vol. 2019, pp. 1–5, Dec. 2019.

[5] M. Gharibi, R. Boutaba, and S. L. Waslander, "Internet of drones," *IEEE Access*, vol. 4, pp. 1148–1162, 2016.

[6] "Automated drone (uav) applications." [Online]. Available: https://www.airoboticsdrones.com/applications/

[7] "Drone-in-a-box solution for port areas protection," Oct 2020. [Online]. Available: https://www.azurdrones.com/autonomous-drone-for-port-areas/

[8] "Ieee standard for data format for blockchain systems," *IEEE Std 2418.2-2020*, pp. 1–32, 2020.

[9] S. Malik, S. S. Kanhere, and R. Jurdak, "Productchain: Scalable blockchain framework to support provenance in supply chains," in *2018 IEEE 17th International Symposium on Network Computing and Applications (NCA)*. IEEE, 2018, pp. 1–10.

[10] R. A. Michelin, A. Dorri, M. Steger, R. C. Lunardi, S. S. Kanhere, R. Jurdak, and A. F. Zorzo, "Speedychain: A framework for decoupling data from blockchain for smart cities," in *Proceedings of the 15th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services*, 2018, pp. 145–154.

[11] R. C. Lunardi, R. A. Michelin, C. V. Neu, H. C. Nunes, A. F. Zorzo, and S. S. Kanhere, "Impact of consensus on appendable-block blockchain for iot," in *Proceedings of the 16th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services*, 2019, pp. 228–237.

[12] G. S. Aujla and A. Jindal, "A decoupled blockchain approach for edge-envisioned iot-based healthcare monitoring," *IEEE Journal on Selected Areas in Communications*, 2020.

[13] M. Singh, G. S. Aujla, and R. S. Bali, "Odob: One drone one block-based lightweight blockchain architecture for internet of drones," in *IEEE INFOCOM 2020-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*. IEEE, 2020, pp. 249–254.

[14] M. Uddin, A. Stranieri, I. Gondal, and V. Balasubramanian, "A survey on the adoption of blockchain in IoT: Challenges and solutions," *Blockchain: Research and Applications*, p. 100006, Feb. 2021. [Online]. Available: https://doi.org/10.1016/j.bcra.2021.100006

[15] Z. Zheng, S. Xie, H.-N. Dai, X. Chen, and H. Wang, "Blockchain challenges and opportunities: A survey," *International Journal of Web and Grid Services*, vol. 14, no. 4, pp. 352–375, 2018.