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BloCoV6: A blockchain-based 6G-assisted UAV contact tracing scheme for COVID-19 pandemic

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***Abstract*— In this article, the authors propose a scheme, *BloCoV6*, that integrates sixth-generation (6G)-assisted unmanned aerial vehicles (UAVs) and blockchain (BC) to monitor mass surveillance of persons in dense areas, and implement a trust-based contact-tracing ecosystem in BC. The scheme operates in two phases. In the first phase, based on the area density, and the number of users, UAVs swarms are mounted with thermal imaging sensors that monitor the body temperature of persons. The collected data are sent to ground stations in real-time, through 6G network services. Once, the images are analyzed, the details of potential COVID-19 patients are identified, and their travel and contact records are fetched and stored in BC. Then, in the second phase, the contact-tracing information is validated in BC. The proposed scheme is simulated for smart contracts (SC) functionalities, UAV observations, latency, spectral efficiency, and transaction and signing costs. The obtained results indicate the scheme viability. For example, 6G has a low latency of *330.8* milliseconds (ms), which outperforms *1200.1* ms in fifth-generation (5G) channels. The observed spectral efficiency of 6G channels *is 5−10*× higher than 5G, and the average signing and transaction cost is *3.473* seconds (s), and *6.873* s respectively, which outperforms the conventional schemes.**

***Keywords*— Blockchain, 6G, UAV, Contact Tracing, Data dissemination.**

I. INTRODUCTION

Recently, the world has witnessed a surge in cases of Novel Coronavirus (COVID-19). It is estimated that the COVID-19 virus is a successor to Severe Acute Metastasis Syndrome Coronavirus, a pair of (SARS-CoV-2) virus, and the transmission of COVID-19 triggered considerable changes in the lifestyle of populations worldwide. By mid of March 2021, more than 117,000,000 positive cases were registered in total, resulting in more than 2,000,000 deaths [1]. The World Health Organisation (WHO) proclaimed COVID-19 to be a pandemic due to its terrible degree of global unfolding. COVID-19 spreads during close contact communication between people. To mitigate the spread, it is mandated that a person should maintain at least 1 meter (3ft) distance [2]. To leverage mass scale monitoring of COVID-19 cases, advanced technologies help societies to provide driving solutions. One key technical driver is the usage of unmanned aerial vehicles (UAVs). UAVs assist in multiple ways, such as monitoring body temperature, heart rate, respiratory rates, delivering supplies to the infected person, monitor social distancing, and goods delivery to the consumers [3]. In UAVs, data is managed and accessed through a distributed database interfaced through a common driver to the external system components. This allows efficient data processing and dissemination in the network. UAVs require a strong network connection for communication. Right now, the fifth-generation (5G) network is worthwhile for communicating with/between UAVs. 5G supports a communication bandwidth of 20 Gbps, reduced latency of $< 1ms$, through tactile internet service, wider range, higher affordability, and coverage stability in comparison to 4G counterparts [4].

In China and many other countries, a range of 5G+ thermal imaging systems in robotics and UAVs are increasingly used in public spaces to minimize COVID-19 spread [5]. 5G-based UAVs not only offer inspection but also provide medical supplies in difficult terrain zones. However, with increasing users, and dense user traffic, the 5G communication would face bottlenecks in the near future. The 5G communication spectrum is limited and allows frequency waves to travel only short distances, which inherently limits the mobility and power consumption of densely networked nodes and increases the computing overheads of UAV networks. Moreover, to promise ubiquitous and dense sensor connectivity, 5G networks would require intelligent sensing and cognition [6].

To address the limitations of 5G computing, researchers globally have shifted towards sixth-generation (6G) networks. 6G promises the convergence of intelligent network orchestration, with high connectivity, mobility, and sense, through a range of offered services. 6G supports

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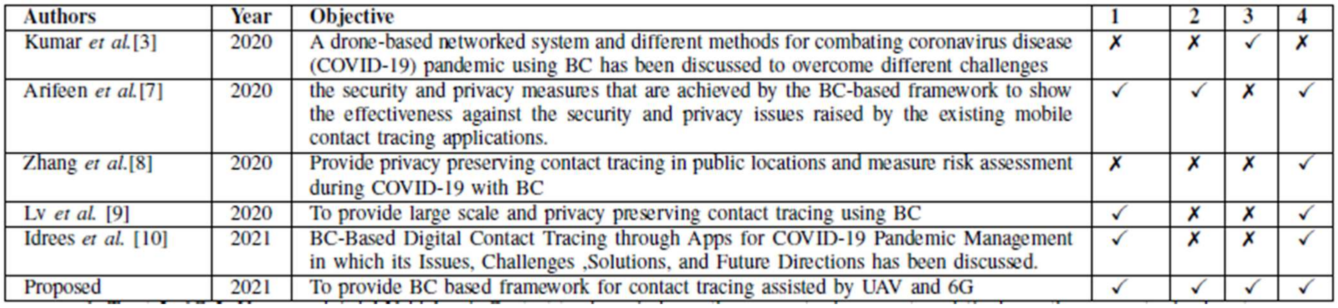
emerging features like network densification, massive throughput, extremely high reliability, ultra-low-latency, less energy consumption, high spectral efficiency, and ubiquitous massive connectivity. Moreover, 6G is envisioned to integrate technologies like artificial intelligence (AI), smart wearables, BC, implants, autonomous vehicles, computing reality devices, sensing, and three-dimensional (3D) mapping. 6G would maximize quality-of-service (QoS) many folds and promises high data rates of 1 Tbps, ultra-low latency 0.1 ms, and reliable communication between the two entities. However, as the communication is established over open channels, and data is stored and shared through centralized ecosystems, it is vulnerable to single-point failures, mirroring, and privacy attack vectors. Thus, an inherent decentralization is required for secure access and storage of data, with mirroring-based support to increase redundancy and reliability of the ecosystems. To ensure trust and consistency in stored data on decentralized nodes, BC is a viable choice [11]. As BC is an integral part of the 6G protocol stack, it makes it easy to integrate and communicate with legacy 5G services.

TABLE I: Comparative analysis of the proposed scheme with relevant state-of-the-art schemes



Authors	Year	Objective	1	2	3	4
Kumar *et al.*[3]	2020	A drone-based networked system and different methods for combating coronavirus disease (COVID-19) pandemic using BC has been discussed to overcome different challenges	✗	✗	✓	✗
Arifeen *et al.*[7]	2020	the security and privacy measures that are achieved by the BC-based framework to show the effectiveness against the security and privacy issues raised by the existing mobile contact tracing applications.	✓	✓	✗	✓
Zhang *et al.*[8]	2020	Provide privacy preserving contact tracing in public locations and measure risk assessment during COVID-19 with BC	✗	✗	✗	✓
Lv *et al.* [9]	2020	To provide large scale and privacy preserving contact tracing using BC	✓	✗	✗	✓
Idrees *et al.* [10]	2021	BC-Based Digital Contact Tracing through Apps for COVID-19 Pandemic Management in which its Issues, Challenges ,Solutions, and Future Directions has been discussed.	✓	✗	✗	✓
Proposed	2021	To provide BC based framework for contact tracing assisted by UAV and 6G	✓	✓	✓	✓

1. Trust 2. 6G 3. Unmanned Ariel Vehicles 4. Contact-tracing ✓-shows the parameter is present, and x - shows the parameter is absent.

Thus, BC would assist 6G to provide security, trust, and chronology in the communication among heterogeneous networked UAVs, and leverage secure communication to the ground station G [12]. UAVs have to make real-time decisions and simultaneously perform various activities like route planning with obstacle avoidance. Thus, in the proposed scheme, BloCoV6, we present an integration of 6G-assisted UAVs and BC for privacy-preserving contact tracing of COVID19 patients through gathered thermal images, and by spotting patients in the vicinity through aerial route.

A. *Motivation*

The motivation of the scheme is as follows:-

- UAV swarms can play a major role in dealing with the COVID-19 pandemic. However, security and privacy is a major concern in software-based multi-swarm UAV, and thus security issues can be addressed through BC. Thus, it addresses the research gaps of earlier approaches through secured access of COVID-19 UAV data through a trust-based ecosystem that allows government agencies and healthcare stakeholders to communicate securely, without external intervention.
- Currently, a lot of research work is being done which is devoted to UAVs for restraining the COVID-19 pandemic. However, most of the work is focused on solutions pertaining to immunity, contact-tracing, monitoring, and quarantine. Very few works have addressed the aspects of communication and security as a coherent unit. Hence, the proposed scheme *BloCoV6* formulates a real-time solution that can effectively monitor and trace patients, keeping the privacy and sanctity of patients intact.

B. *Contributions*

Following are the primary contributions of the proposed scheme:-

- A BC-based UAV ecosystem for efficient chronology, and traceability of contact tracing of potentially affected COVID-19 patients.
- A 6G-assisted network model that allows fine-tuned orchestration of network parameters and leverage UAVs to exhibit extremely low latency, dense sensor integrations, and massive data-dissemination for affected zones in COVID-19 pandemic.
- SCs are proposed based on specific functionalities like user registrations, contact list updates, UAVs and hospital registrations for medical supplies, and mass surveillance, COVID-19 positive patient detection, and automated notification to COVID-19 patients for self-isolation.

C. *Article Structure*

The paper is organized into five sections. Section II presents the existing state-of-the-art schemes. Section III presents the proposed 6G-assisted network model to support the scheme, and section IV discusses the proposed scheme. Section V presents the performance evaluation of the scheme against existing conventional approaches. Finally, section VI concludes the paper.

II. STATE-OF-THE-ART

The section presents the related state-of-the-art schemes related to the integration of UAVs, network communication, and security schemes in data transfer. A comparative analysis of relevant schemes with the proposed scheme is presented in Table I. Na *et al.* [13] presented UAV communication assisted through cooperative non-orthogonal multiple access (CNOMA) systems on the backdrop of 6G-enabled IoT. In the scheme, the proposed problem is non-convex, and solutions are provided through an iterative algorithm with stable convergence. Authors in [14] addressed various challenges and opportunities related to the usage of BC in 6G. Authors in [15] presented the possible deployment of BC for mitigation of cyber-attacks on UAV swarms. In the simulation, they have proposed solutions about data privacy and confidentiality for permissioned networks through the hyperledger fabric on UAV swarms. Rana *et al.* [16] presented BC-assisted solutions to improve drone monitoring and presented a generic scheme that increases network connectivity through an access-control ecosystem. Chamoli *et al.* [17] presented a comprehensive survey on the integration of 6G and BC to present COVID-19 inspection and monitoring solutions.

III. BLOCOV6: NETWORK MODEL

The section presents the discussion on the proposed network model of the *BloCoV6* scheme. Fig. 1 presents the details. We consider an entity set $E=\{P,D,A,G,U,H,V\}$, where P denotes the set of people in area B. A is an application running on a person's P device D. U is the set of UAVs that are assigned the monitoring task of P. The data collected by U is stored in G with memory chips. H is the hospital entity and V is the chain validators, validating blocks added in BC.

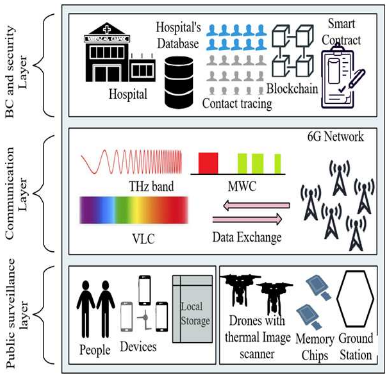


Fig. 1: *BloCoV6*: Network Model

A. Layer 0: Public surveillance layer

In this layer, UAVs identify persons that might be infected with the help of thermal imaging, on a surveillance B, P consists of n persons denoted as follows.

$$P = \{p_1, p_2, \ldots, p_n\} \quad (1)$$

Each P is having a device set, denoted as $D = \{d_1, d_2, \ldots, d_n\}$ and running parallel applications $A = \{a_1, a_2, \ldots, a_n\}$ respectively. On installation of A, a random user ID and password is generated that represents the device's identity for the application and assisted Services. It also generates a notification token that is unique and is used to provide notifications. In case of contact between two different users p_q and p_r, an alias ID is sent to the contact's device and vice versa. Here, every D generates a unique encrypted ID, denoted as $ID\{id_1, id_2, \ldots, id_n\}$ of each P using A. Hence, the total number of respective entity sets are equal, denoted as follows.

$$P_{total} = D_{total} = A_{total} = ID_{total.} \quad (2)$$

In area B, we assume m UAVs are operational, denoted as follows.

$$U = \{u_1, u_2, \ldots, u_m\} \quad (3)$$

With the constraints,

$$m < n \quad (4)$$

Here, every UAV stores data in an individual chip. In the given scheme, it is assumed that the UAVs are designed to fly in a three-dimensional vector space with coordinates x,y,z at a given time instant t, denoted as $[x(t), y(t), z(t)]$, where $x(t)$ and $y(t)$ are parallel to the ground coordinates, and $z(t)$ is the vertical height of the UAV. If an angle of projection of the UAV is θ from the ground g, and the initial speed is s at a given time instant t, then $x(t)$ and $y(t)$ can be presented as follows.

$$\begin{gathered} x(t) \leftarrow s(t)Cos(\theta(t)) \\ y(t) \leftarrow s(t)Sin(\theta(t)) \end{gathered} \quad (5)$$

The flying range of UAV, denoted as R is specified as follows.

$$R = \frac{s^2 Sin(2\theta)}{g} \quad (6)$$

Now, UAV-based cameras are designed with camera sensors to capture the P's image I. Through I, social distancing measurements and density-based thermal imaging can be measured [3]. Here, the camera sensor detects the person's thermal image display and measure the temperature T of P. If the captured image I is not clear, then it is made clear through detection and unit systems. Here, U stores the data in memory chips under the following constraints,

$$C1 : T > T_{threshold} \quad (7)$$

where, $T_{threshold} = 100 \circ F$.

The AI-based drones are used and they rely mainly on computer vision techniques to detect flying objects, and analyze the information and send results to ground stations [18]. Sensors are used to collect the data that is processed by UAVs, which includes visual, positioning, and environmental data. This data is then fed to machine learning models to determine the response a UAV should have to vary environmental conditions, and objects UAV should prioritize or avoid, and the flying paths.

B. Layer 1: The communication Layer

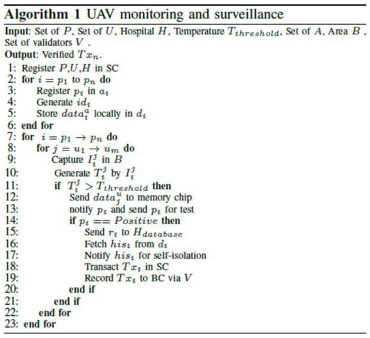
At *Layer 1*, we present the details of 6G communication systems used to exchange the information between the UAVs, G, and the BC layer. 6G allows tera-hertz spectrum bands, which is perfectly suitable for latency-aware applications. 6G assists Key characteristics of 6G communication channels are ultra-reliability (10^{-9}), massive ultra-low latency ($< 100\mu s$), high data rate ($> 1Tbps$), high spectrum efficiency (3–10× over 5G), and high connection density $10^7/km^2$. 6G operates at spectrum bands with the frequency of $95GHz$–$3THz$, which allows responsive and real-time orchestration over 5G. Through massive frequency bands in millimeter Wave (mmWave) bands, in 6G, the ultra-high data transmission rate can be supported to assist UAVs. Through flexible beamforming models, UAV mobility is assisted in 6G through mmWave beam-forming with phased arrays, in small dense cells with low power and high spectral efficiency [19].

C. *Layer 2: BC and Security Layer*

At *Layer 2*, the security of shared data through UAVs is assisted. As depicted in eqn. (7), p_n detected as potential COVID-19 infected, would be notified on a_n. Based on the notification, p_n has to visit nearby H for COVID-19 tests. In case the report is positive, then the report is stored in a database $H_{database}$ [7], The stored data in d_n would be transacted through SCs for contact tracing. As the traced contacts have alias ID and the contacted users, actual ID relation is stored in the local storage server [8] of a_n. The data is now be added to the BC validated as follows.

$$V = \{v_1, v_2, \ldots, v_f\} \quad (8)$$

where f is the total number of peers. A BC consists of V and they are responsible for validating the added transactions. As every peer is not part of the consensus mechanism, thus, they become free to choose and participate as validators V. Once V validates the added transactions, every node keeps the copy of the transaction record and adds the same to the chain structure.



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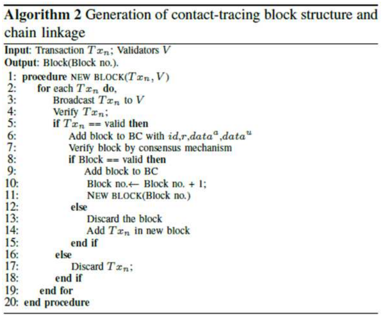
Algorithm 1 UAV monitoring and surveillance
Input: Set of $P$, Set of $U$, Hospital $H$, Temperature $T_{threshold}$, Set of $A$, Area $B$ ,
Set of validators $V$ .
Output: Verified $Tx_n$.
Register $P$,$U$,$H$ in SC
for $i = p_1$ to $p_n$ do
    Register $p_i$ in $a_i$
    Generate $id_i$
    Store $data_i^a$ locally in $d_i$
end for
for  $i = p_1 \rightarrow p_n$ do
    for $j = u_1 \rightarrow u_m$ do
        Capture $I_i^j$ in $B$
        Generate $T_i^j$ by $I_i^j$
        if $T_i^j > T_{threshold}$ then
            Send $data_j^u$ to memory chip
            notify $p_i$ and send $p_i$ for test
            if $p_i == Positive$ then
                Send $r_i$ to $H_{database}$
                Fetch $his_i$ from $d_i$
                Notify $his_i$ for self-isolation
                Transact $Tx_i$ in SC
                Record $Tx_i$ to BC via $V$
            end if
        end if
    end for
end for
```



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Algorithm 2 Generation of contact-tracing block structure and chain linkage
Input: Transaction $Tx_n$; Validators $V$
Output: Block(Block no.).
procedure NEW BLOCK($Tx_n, V$)
    for each $Tx_n$ do,
        Broadcast $Tx_n$ to $V$
        Verify $Tx_n$;
        if $Tx_n$ == valid then
            Add block to BC with $id$,$r$,$data^a$,$data^u$
            Verify block by consensus mechanism
            if Block == valid then
                Add block to BC
                Block no.← Block no. + 1;
                NEW BLOCK(Block no.)
            else
                Discard the block
                Add $Tx_n$ in new block
            end if
        else
            Discard $Tx_n$;
        end if
    end for
end procedure
```

IV. BLOCOV6: THE PROPOSED SCHEME

The section presents the details of the scheme. In the proposed scheme, we present a proposed COVID-19 contact tracing algorithm, based on detected users from 6G-assisted UAVs for communication. In the proposed scheme, p_n registers to the BC network through cryptocurrency application a_n. Initially, an encrypted user ID which is generated for the n^{th} user denoted as ID_n. The stored data of the n^{th} user is then made available on the application as follows.

$$data_n^a = \{id_n, add_n, No_n, his_n\} \quad (9)$$

where add_n is the user address, No_n is the user contact number, and his_n is the recent contact tracing history list of probable COVID-19 infected person in last week. Fig. 2 highlights the flow of the proposed scheme.

Based on the contact history of the infected COVID-19 patient, the historical transactions are presented as follows.

$$his_n = \{l_1, l_2, \ldots, l_z\} \quad (10)$$

Here, l_z is the z^{th} person p_n came in contact with. After this, the UAV surveillance starts and U records thermal images T, as per the constraints presented in eqn. (7). The collected thermal image of the p_n recorded in u_m. Now, a notification is sent to the p_n's device d_n, and the concerned person has to visit H for COVID-19 testing.

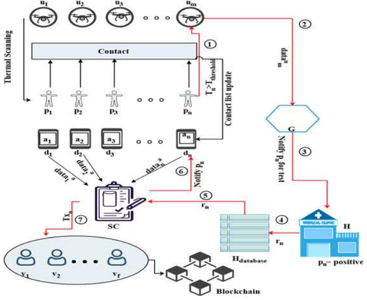


Fig. 2: Information flow of the proposed scheme

In case the reports r_n of p_n are *POSITIVE*, it would be stored in $H_{database}$, and a transaction Tx_n would be initiated. The details are presented in algorithm 1. The recorded transaction in BC would comprise of the following fields

$$Tx_n = \{id_n, r_n, data_n^a, data_m^u\} \quad (12)$$

Fig. 3 presents the details of the block structure [7]. After successful Tx_n generation, Tx_n is passed to V to add it into BC. Algorithm 2 depicts the process of addition of the block structure and chain linkage.

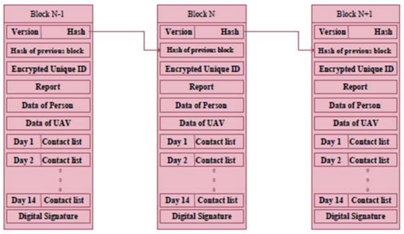
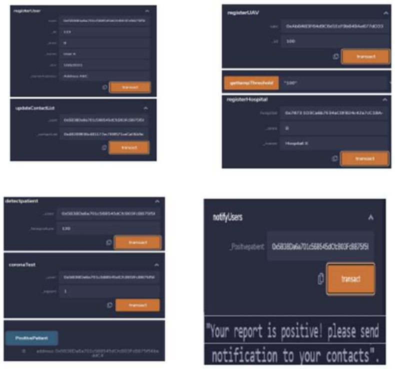


Fig. 3: The details of contact-tracing block structure [7]

TABLE II: Simulation Parameters

Parameters	Specification
UAVs	2 Units
Thermal Image camera	2 Units
Digital thermometer	2 Units
No. Of days	4 Days
No. of Hours/Day	6 Hours
$T_{threshold}$	$100^{\circ}F$



"Your report is positive! please send notification to your contacts".

Fig. 4: The proposed SC functionalities in *BloCoV6* scheme (a) User Registration and contact List Update, (b) UAV and Hospital Registration (c) Positive patient detection via UAVs and Hospital, and (d) Notify Users for self-isolation

V. BLOCOV6: PERFORMANCE EVALUATION

This section presents the performance evaluation of the proposed scheme compared to the traditional methods. For the scheme setup, we have considered infrared and digital sensors mounted on UAVs. For simulation results, we have used the Anaconda Navigator (Conda *v4.9.2*) and Python *v3.7.3*.

A. Experimental Setup

For the experimental setup, we have selected a public area and deployed 2 UAVs with thermal image cameras. Along with this, we have appointed 2 persons to check the temperature with the help of a digital thermometer. The observation process was held for 4 days, 6 hours each. The parameters of the experiment are shown in Table II.

B. Smart Contract Functionalities

To delineate the SC functionalities, we propose the SC on Remix IDE *v*0.6.0, shown in Fig. 4. Our SC includes four functions for contract tracing. As shown in Fig. 4 (a), the first phase is user registration and contact list update. In this, every p_n needs to register itself on the BC platform by providing its address, name, and contact number using a_n. Then, a_n generates an encrypted *ID* for each registered p_n. The *ID* is unique for each user and is not shared with any other user. Now, every p_n will have to update their contact list on the regular basis. As shown in Fig. 4 (b), AI-enabled $u_n$registers itself and will get the $T_{threshold}$ of p_n and if the T is detected above $100^{\circ}F$ then p_n will get a notification through a_n and will have to go for a test to a registered H. Then H will conduct a test and if the test r_n of p_n is positive(1 for positive 0 for negative) after the test, then r_n will be generated and the data of p_n will be updated in $H_{database}$ as shown in Fig. 4 (c). All the users, who were in the contact list of p_n will be notified for self-isolation as shown in Fig. 4 (d).

C. Simulation Results

The section now presents the simulation results. Firstly, we propose the UAV detection results based on massive surveillance of P through T. Then, we delve into 6G network parameters and present the latency comparison of 4G, 5G, and 6G channels with the increase in device density. Next, we present the results based on UAV spectral efficiency on basis of 6G enhanced ultra-reliable low-latency service (ERLLC), compared to 5G ultra-reliable low-latency services (uRLLC). Finally, we present the transaction and signing costs of contact tracing block additions, based on possible COVID-19 patient history. The details of the results are presented in Fig. 5.

As shown in Fig.5 (a), in a public area, the number of people with $T > T_{threshold}$ is recorded. We consider the monitoring through physical infrared thermometers, and UAV drone monitoring, and it is found that UAVs offer better accuracy, due to larger coverage. For the same, we have considered the observation of 4 days on a specific monitoring area, It is observed that data collected by UAVs is ≈ 2 times as compared to conventional infrared measurements. The recorded data by UAVs is 125 observations, while the infrared thermometer can record only 61 observations. As UAVs can cover a large range, hidden areas, the efficiency of data collection is higher.

Next, we move to communication parameters-based analysis. In Fig. 5 (b), we presented the end-to-end latency of 4G, 5G, and 6G networks, which are $20 - 30ms$, $1ms$, and $0.1ms$ respectively. Due to higher latency of 4941 ms, 4G networks would face bottlenecks and network congestion in densely crowded areas. For ≈ 3000 $U + D$, 5G has a low latency of $1200.1ms$, which is 4× better compared to 4G. 6G outperforms both 4G and 5G, with an end-to-end latency of $330.8ms$ for 3000 $U + D$.

Next, we present the measurement of UAV spectral efficiency. Spectral efficiency is denoted as γ and is presented as follows.

$$\gamma = T/C \times A \qquad (13)$$

where T is the observed traffic by UAV, C is the channel bandwidth, and A is the coverage area. Fig. 5 (c) presents the details. We considered the processing latency as the dominant factor and thus compared the 6G ERLLC service with the 5G-uRLLC service. 6G-ERLLC has ≈ 5−10× higher γ than the corresponding 5G-urLLC, and thus the spectral efficiency is higher. Thus, 6G-assisted UAVs have better coverage and network lifetime and can disseminate information at higher distances than their 5G counterparts.

Next, we present the average signing and transaction costs of mined contact-tracing blocks. Fig. 5 (d) presents the observations. The average signing cost of the scheme is 3.473 seconds, and the verification cost 6.873 seconds. The low costs can be attributed to the fact that COVID-19 contact tracing information is disseminated over 6G channels that have high user throughput. Thus, the contact tracing information is fetched in less time than 5G channels.

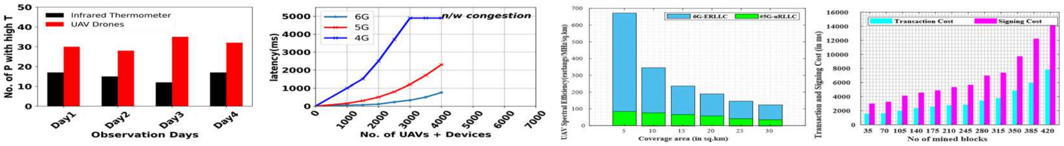


Fig. 5: Simulation Results of *BloCoV6* scheme: (a) Number of *P* detected by *U* by infrared thermometer, (b) End-to-End Latency for 4G,5G, and 6G networks (c) Comparison of UAV Spectral Efficiency of 6G-ERLLC and 5G-uRLLC service, and Transaction and Signing Cost of COVID-19 contact-tracing blocks

VI. CONCLUSION

The paper introduces a scheme, *BloCoV6* that integrates key 6G-assisted UAVs with BC for contact-tracing of COVID19 patients. The scheme proposes an efficient contact tracing ecosystem based on low-latency, and high-reliability of networked UAVs to reduce the human interventions, and perform massive surveillance of temperature sensing of persons through thermal sensors. The scheme proposes an efficient network model that integrates BC and 6G-UAVs and proposes two algorithms for UAV monitoring, and contact-transparency, and trust between multiple authorities. Once the patient gets detected, A notification of self-isolation is generated and SCs are executed. The proposed results show the viability of the scheme.

As part of the future work, the authors would investigate the effect of deep learning algorithms on thermal images to predict the overall impact of COVID-19 spread on the entire area covered by the 6G channel. In case of high probability, the contact-tracing of users can be notified earlier to concerned authorities and mined blocks of contact persons would be added with real-time response, thereby further reducing the effect of COVID-19 spread.

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