COVICT: an IoT based architecture for COVID-19 detection and contact tracing

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Abstract
The world we live in has been taken quite surprisingly by the outbreak of a novel virus namely SARS-CoV-2. COVID-19 i.e. the disease associated with the virus, has not only shaken the world economy due to enforced lockdown but has also saturated the public health care systems of even most advanced countries due to its exponential spread. The fight against COVID-19 pandemic will continue until majority of world’s population get vaccinated or herd immunity is achieved. Many researchers have exploited the Artificial intelligence (AI) knacks based IoT architecture for early detection and monitoring of potential COVID-19 cases to control the transmission of the virus. However, the main cause of the spread is that people infected with COVID-19 do not show any symptoms and are asymptomatic but can still transmit virus to the masses. Researcher have introduced contact tracing applications to automatically detect contacts that can be infected by the index case. However, these fully automated contact tracing apps have not been accepted due to issues like privacy and cross-app compatibility. In the current study, an IoT based COVID-19 detection and monitoring system with semi-automated and improved contact tracing capability namely COVICT has been presented with application of real-time data of symptoms collected from individuals and contact tracing. The deployment of COVICT, the prediction of infected persons can be made more effective and contaminated areas can be identified to mitigate the further propagation of the virus by imposing Smart Lockdown. The proposed IoT based architecture can be quite helpful for regulatory authorities for policy making to fight COVID-19.

Keywords COVID-19 · Pandemic · Early identification · Contact tracing · Internet of things · D2D communication · Smart lockdown

1 Introduction
The year 2020 will be remembered in the history forever due to the spread of a novel virus namely SARS-CoV-2. As of Sept 29, 2022, this virus outbreak has infected around 617 million people around the globe with 3.8 million people infected in a single day. The Omicron has proved to be the most contagious variant discovered so far. The pandemic has changed the life of every living creature on the planet due to enforced lock downs, social distancing, online education, work-from-home, remote examination and treatment of regular patients (Ahmed et al. 2020b; Sohrabi et al. 2020; Nicola et al. 2020; Sukcheva et al. 2021). The effects of COVID-19 on the lives of people around the globe are portrayed in Fig. 1. The main theme behind hard measures taken by governments and regulatory bodies is to reduce the Reproduction Number (R0) so called flattening the curve until the development of a vaccine. However, the spread of this virus

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can also be slow down with the help of technology through early prediction of potential cases (Otoom et al. 2020; Singhal 2020).

COVID-19 pandemic can be classified into four stages of transmission as explained by World Health Organization (WHO) (Chamola et al. 2020; Jiang et al. 2020). The first stage is related to spread of the disease due to the patients with travel history to a contaminated area. Early screening and isolation of imported patients can halt the spread of the cases. In second stage, disease is spread locally by the imported patients. Efficient contact tracing and quarantining the infected persons can mitigate the spread of virus at large scale. The third stage of virus outbreak occurs when the spread of the disease is extended within an area geographically. Mandatory lockdown of the affected area can limit the outbreak of virus from reaching the final stage. The fourth and last stage of a pandemic is linked with the large-scale spread of the virus in any country. Effective vaccine can help only in curbing the spread of the disease at this stage.

The main cause of transmission and spread of the virus is physical contact. Small droplets that are generated as a result of sneezing, talking and coughing are the main carriers of the virus. These droplets can potentially cover a distance of approximately 6 feet. The worst part of it is that these droplets can also contaminate the surfaces of surrounding objects that can also spread the virus. Clinical investigations show that virus can live on steel, plastic, metals and card-boards for several days (Chamola et al. 2020; Huang et al. 2020). Cough, fatigue, fever, shortness of breath, lost of taste and smell are the main symptoms of COVID-19. The incubation period of COVID-19 is 14 to 21 days (Roy et al. 2020; Shereen et al. 2020).

The need of the hour is to devise communication based solutions to detect, track and alert health authorities wirelessly to take effective measures in curbing the spread of the virus (Roy et al. 2020; Soldani 2020). The development of Internet of Things (IoT) can address this matter quite effectively and efficiently. IoT comprises of small objects or Things that are linked together to form a network. These Things are capable of sensing and processing the collected data. The role of IoT in healthcare systems is quite impressive due to its data collection, computation, identification and tracing capabilities (Al-Fuqaha et al. 2015; Habibzadeh et al. 2019; Darwish et al. 2019).

In context of current pandemic, real time symptom data collection by an IoT device can effectively detect potential infected people. Early detection can help in an effective treatment of patients, mitigating spread of virus and eventually saving more lives. IoT devices can quickly detect the symptoms by sensing and are capable of analyzing the data for healthcare authorities to control the transmission of virus (Kumar et al. 2020a; Nasajpour et al. 2020; Ndiaye et al. 2020; Wynants et al. 2020). In addition to symptoms data, location and travel history are also essential parameters for further clinical investigations and testing. Information about travel history of a suspected case is very essential due to unavailability and in feasibility of large-scale testing (Chamola et al. 2020; Iwendi et al. 2020; Ndiaye et al. 2020).

Artificial Intelligence (AI) has performed remarkably well besides IoT in combating this outbreak. AI is a technology that enables computers to emulate intelligence of human to process things such as Machine Learning, Augmented Reality, Virtual Reality, etc. ML being a subset of Artificial Intelligence are algorithms that process data for decision making and prediction. Decision tree, Random forest, K-nearest neighbour, hidden Markov models, Support vector machine, Naive Bayes, etc are methods of traditional ML. (Maghdid et al. 2020; Chen et al. 2020). In context of COVID-19, different ML algorithms can be used to determine the suspected cases on the basis of onset of symptoms, travel history and confirmed cases exposure (Nguyen 2020; Kumar et al. 2020a; Maghdid et al. 2020).

COVID-19 patients are sometimes asymptomatic but can transmit virus to the persons who came in contact (Jiang et al. 2020). That is where a process called “Contact Tracing” is required to track the people in close contact of the positive case as they might be at risk of being infected (Kretzschmar et al. 2020).

Contact tracing is normally done by the health-care team and is achieved by interviewing the affected person to track the persons who came in close contact with him during the incubation period of COVID-19 (Ahmed et al. 2020b). The tracked persons are then quarantined or tested if necessary to stop the spread. However, this is quite challenging because it is difficult to recall each and every contact for the last 3 weeks (Kretzschmar et al. 2020). Besides, the index case might have infected other persons whom he cannot even identify e.g. persons standing in the bank or super market.
Any delay in this manual tracking can increase the spread further (Otoom et al. 2020; Cheng et al. 2020).

Moreover, IoT based solutions can be adopted to track close contacts of the infected people. The IoT devices detect proximity and location with their inbuilt Bluetooth interfaces and GPS. These devices save data of the contacts that can be used by health authorities later on for tracing (Ahmed et al. 2020b; Kretzschmar et al. 2020). The ability of the smart phones of tracking their own location and the location of nearby devices makes them quite suitable for contact tracing. This results in the development of contact tracing apps for smart phones (Kumar et al. 2020b; Ahmed et al. 2020b).

COVID-19 has affected the people around the globe. Due to its severe and contagious nature, the first and foremost critical issue in COVID-19 is to diagnose it timely and cutting off the chain of transmission by isolating the susceptible and patient. The motivations of this research are itemized as follows.

- **Early Diagnosis**: Early diagnosis is the first line of defence against corona virus. Early detection of potential patients allows the healthcare authorities to take remedial measures to minimize the spread of the virus. Real-time data collection of individual symptoms through different wearable sensors helps the remote health physician in quick identification of the infectees.

- **Contact Tracing**: Contact tracing is by large one of the most effective measure to contain COVID-19 outbreak. In specific, contact tracing is described as the ability to reconnect the contact chains of infected persons. Contact tracing is performed by the health-care authorities by interviewing the patient to trace his close contacts during the incubation period. The close contacts are then quarantined or tested to minimize the spread. The delay in the manual tracing can cause the virus to spread further. To handle the situation, researchers have focused to develop contact tracing apps for automatic tracing of close contacts.

- **COVID-19 Management System**: A centralize system monitors the virus spread on the basis of the data provided by the healthcare center. The system also manages supply of face masks, hand sanitizers, PPEs, testing kits and other items on the basis of data provided by the health authorities. The Governing authorities will make decisions like Smart lockdown, Supply chain management, Gradual and safe reopening of economic sectors, etc accordingly.

The contact tracing apps have been facing challenges in large-scale adoption in many countries. Apart from inter-apps and OS versions compatibility, privacy concerns are influencing their full-scale adoption the most (Redmiles 2020; McLachlan et al. 2020; Garg et al. 2020). The health officials are using these app data in conjunction with manual tracing to track contacts effectively.

This paper proposes a COVICT framework which is an IoT based COVID-19 detection, monitoring and semi-automated contact tracing system.

### 1.1 Salient features of COVICT framework

The salient features of the proposed COVICT framework are briefly narrated as follows:

- An IoT-based architecture has been proposed for detection, monitoring and tracing of potential COVID-19 patients in real time.
- Artificial Intelligence and Machine Learning based IOT framework is effective to predict and early detect the COVID-19 patients.
- A Secure and privacy preserving tracking of contacts at high risk is attained by using Device-to-Device communication.
- Assists Government authorities in outbreak management and policy making to fight COVID-19.

### 1.2 Paper structure

Section 2 reviews the relevant literature. The proposed COVICT framework has been discussed in Sect. 3. Section 4 focuses on prediction of potential Covid-19 cases using machine learning algorithms. In Sect. 5 we have discussed challenges, limitations and future recommendations for the implementation of this framework. Lastly, Sect. 6 concludes the work.

### 2 Literature review

First, we will discuss AI and IoT-based solutions for prediction and monitoring of cases in COVID-19. Then we will conclude our discussion in this section with importance of Contact Tracing in COVID-19.

#### 2.1 AI and IoT-based solutions for prediction and monitoring of COVID-19 cases

COVID-19 outbreak has affected the world in every field of life. Schools, universities, industries, offices and governments are looking for new strategies and technologies to continue their routine works. Siriswardhana et al. (2020) provided IoT and 5G-based solutions in the field of symptoms detection, contact tracing, telehealth, education, remote offices and e-tourism along with their challenges and technical requirements.
COVID-19 outbreak has been declared a pandemic by WHO. Effective social distancing and tracking of infected persons can help significantly in mitigating the spread worldwide. Health authorities require individual’s data for managing the COVID-19 pandemic. The required data comprises of real-time symptoms, travel history and location. These basic parameters set the basis for further clinical investigations. Health authorities in many countries like Germany, France, Switzerland, Fiji and Nigeria have implemented SORMAS for tracking end to end infections. The coronavirus pandemic (2021) is a Surveillance Outbreak Response Management and Analysis System invented and tested in Nigeria in the wake of Ebola epidemic 2014. After identification of suspected cases, the healthcare authorities log them into a system. After confirmation through lab tests, close contacts of confirmed cases are recorded in a single system that is accessible to both healthcare staff and government authorities. This allows them to have a complete picture of disease spread. Necessary measures such as treatment, quarantine and lockdown are quickly taken to curb the spread of the disease.

IoT-based solutions have made remarkable advancements in the field of healthcare. COVID-19 pandemic has posed a great threat to global healthcare systems. IoT-based devices and applications are being used in the three main phases of COVID-19. In diagnosis phase, IoT based biosensors help in lowering the COVID-19 transmission by early detection of patients. In second phase namely quarantine period, IoT based wearable and disinfection devices can help in remote monitoring of patients. IoT based crowd density and safe distance monitoring devices can play their part in important after patient recovery phase. Nasajpour et al. (2020) surveys the part of technologies based on IoT in battling COVID-19 in early detection, quarantine period and after patient recovery phases.

Besides IoT, Artificial Intelligence has also made impressive achievements in our day-to-day lives in a number of ways. AI and machine learning are also playing a decisive role in battling against this current COVID-19 pandemic. Methods based on machine learning are deployed to gain knowledge about the virus symptoms on the basis of data collected. This is a cost-effective and efficient detection technique as compared to expensive testing kits method. This is conceivably feasible because data collected from integrated sensors in smartphones have been used effectively in many applications. For example, fingerprint sensor can predict fever levels. images captured and videos taken by a smartphone can detect human fatigue and nausea. Similarly, audio data from a smartphone microphone can detect cough. The predictions made by AI methods can support authorities in making the virus containment decisions and supply chain management. In this context, Nguyen (2020) surveys AI methods that can be utilized in different applications for fighting COVID-19 pandemic.

Most of the countries in the world at the present are dealing with large outbreak of COVID-19 due to local transmission. Currently USA, Russia, Brazil and India are facing such scenario. These hard stricken countries need testing on large scale. Unfortunately due to in feasibility of testing at large scale and insufficiency of testing kits, health authorities need testing on priority basis as per CDC guidelines (Shammi et al. 2020; Alsheri et al. 2022). In this context, Chamola et al. (2020) discusses different classes of COVID-19 transmission and the different strategies required for mitigating the virus spread in each stage. The authors highlight use of different technologies like Artificial Intelligence, IoT, Unmanned Air Vehicles and Blockchain to manage the impact of this contagious disease.

COVID-19 outbreak is now spreading exponentially due to which healthcare systems of even the developed countries have been exhausted. As COVID-19 patients are sometimes asymptomatic, virus is transmitted by a number of healthy looking persons. Therefore, infected persons tracing / contact tracing is required to halt the spread of virus. However, IoT-based technologies could facilitate in early detection and contact tracing. Otoom et al. (2020) proposed an IoT-based framework for real-time collection of data from users for early identification of cases, monitoring of patients recovered and analysis of collected data for understanding nature of this novel virus. Hu (2020) proposed an IoT-based architecture for tracing contacts and analyze the containment effectiveness of disease on the basis of epidemiological model supported by stimulation results. Roy et al. (2020) devised an IoT based model for tracking infections and contacts by incorporating real-time detection on the basis of symptoms.

2.2 Contact tracing in COVID-19

Kretzschmar et al. (2020) discussed the importance of contact tracing in flattening the curve. The authors predicted with stochastic mathematical model that automated contact tracing can reduce the Reproduction number of the disease to less than one. They also concluded that reduction in tracing and testing delays can enhance the effectiveness of contact tracing.

Contact tracing is considered as one of the most effective measure to contain COVID-19 outbreak. If being effective, contact tracing can allow the governments to ease-lockdowns. Dar et al. (2020) discussed the issues and challenges that hinders in the wide adoption of the automated contact tracing solutions. The authors proposed a framework to evaluate some contact tracing solutions in terms of their effectiveness, scalability and usability.
COVID-19 outbreak has changed the perception of every human life on earth. COVID-19 patients are sometimes asymptomatic and are sources of transmission before the onset of symptoms. To cater the situation, researchers have developed contact tracing apps for tracing contacts of infected person automatically. Ahmed et al. (2020b) provided first ever comprehensive survey of contact tracing apps. The authors have reported users concerns in the adoption of these apps and outlined future research directions for large-scale adoption of the apps by improving privacy, security and tracing performance. A brief comparison of some famous contact tracing apps has been shown in Table 1.

The aim of contact tracing apps is to reduce the transmission of the disease and break its chains in short times. However, its effectiveness is strongly dependent on its large-scale adoption (Typically 56 percent to 95 percent according to modeling studies). Studies suggest that partly automated contact tracing reports better identification and monitoring of contacts than manual contact tracing. Braithwaite et al. (2020) performed a systematic review of Automated and Partly automated contact tracing in controlling COVID-19.

Device-to-Device communication (D2D) is being considered a promising technology in 5G cellular networks for the improvement of spectrum utilization. D2D allows direct communication between the devices without involving BTS (Jameel et al. 2018). The integration of socially aware IoT and D2D communication has paved the way for Social D2D (SD2D) (Radanliev et al. 2020; Li et al. 2014; Nitti et al. 2019). In SD2D social relationship e.g. Contact History and Social Similarities; is considered as a reliable connection between the devices. In this context Roy et al. (2020) proposes contact tracing using SD2D as contact between two persons with same social relationship that is most likely to occur.

In Table 2 we have discussed multiple features of the existing IoT architectures for COVID such as research aim, technique, dataset and key features. In the article Kolhar et al. (2020), an IoT based framework for cities lockdown is proposed. This study proposed a decentralised IoT-based solution for lockdown difficulties for the residential population in order to minimise floods and adhere to norms. Moreover, the CNN based multi task cascaded framework has been utilized on the face detection dataset.

The QCovSML Rahman et al. (2022) article work on applied machine learning models work. This paper offers a COVID-19 detection method based on complete blood count (CBC) biomarkers and a stacking machine learning (SML) model, which might be a faster and less expensive alternative. Multiple publicly available datasets are used in this study based on CBC biomarkers. In which the largest dataset consist of fifteen CBC biomarkers collected from the 1624 patients admitted at san Raphael Hospital, Italy of the year of 2020. In the article Yang et al. (2019) ocean of thing (OAT) technology is described three layers which consist of data acquisition layer, fog layer, and cloud layer.

### Table 1 Brief comparison of contact tracing apps

| Sr# | Contact tracing app | Objective | Architecture | Enabling technology | OS | Origin |
|-----|---------------------|-----------|--------------|---------------------|----|--------|
| 1   | COVIDSafe | Identifies Positive cases in close contacts | Centralized | Bluetooth | Android/IOS | Australia |
| 2   | TraceTogether | Captures data of close contacts including duration of visit | Centralized | Bluetooth | Android/IOS | Singapore |
| 3   | Aarogya Setu | Identifies Potential cases using online self-assessment and traces contacts using location data | Centralized | GPS | Android/IOS | India |
| 4   | COVIDSafe-PACT | Collects online symptoms and traces contacts including place of contact | Decentralized | Bluetooth | Android/IOS | USA |
| 5   | Hamagen | Determines close contact with Positive cases using GPS technology | Decentralized | GPS | Android/IOS | Israel |
| 6   | CovidWatch | Determines proximity/duration of contact and notifies others about exposures | Decentralized | Bluetooth | Android/IOS | UoA, USA |
| 7   | Epione | Alerts user about exposure in the last 21 days | Hybrid | Bluetooth | Android/IOS | Africa |
| 8   | D2D Jameel et al. (2018) Roy et al. (2020) | Stores data of close contacts on the basis of proximity and contact duration | Centralized/Decentralized | Bluetooth/GPS/UWB | Android/IOS | Worldwide |
A summary of relevant literature has been shown in Table 3. In this paper, we have proposed a smart IoT-based COVICT architecture for early detection of suspected cases (on the basis of real-time symptoms) and semi-automated contact tracing on the basis of proximity and contact time duration. Our work is different from other frameworks in a way that proposed D2D-based contact tracing scheme is more secure and efficient. Secondly our framework can be efficiently applied in the first three stages of COVID-19 transmission to mitigate its spread. The stimulation results can be used for identification of potential cases as per real-time symptoms. In Angurala et al. (2020) an approach for IoT assisted drone based COVID-19 architecture is proposed. The strategy described in this research employs drone service to limit the danger of infection to physicians and other medical personnel, hence avoiding disease transmission. Moreover, in this study, COVID-19 diseases data set was considered with the concept of clustering.

In Liang et al. (2020) the interoperable IoT architecture based on COVID-19 is proposed. This paper works on design and development of real time situational awareness system, Person to key risk assessment for indoor COVID-19 through open geo spatial standards. The images data is used to train the advance deep learning model i.e. YOLOV3 and CNN. This study Aman et al. (2021) presents a complete review of IoMT in the context of the COVID-19 pandemic, including technological development, acceptance, and prospects, as well as security considerations linked to IoMT in general. During this pandemic time, the majority of IoMT systems have been used largely to monitor and trace infected persons as digital surveillance, which has raised some privacy concerns, but this has been viewed as a necessary evil and is accepted by many residents worldwide. As a result, ongoing discoveries in the field of IoMT security have been comprehensively addressed in this article, including research based on newer technologies such as blockchain to reduce security dangers to persons and systems.

In this study Ahmed et al. (2020a), For early COVID-19 evaluation, an IoT-based deep learning system has been proposed. The framework is capable of alleviating the workload of medical experts/radiologists by detecting infection in chest X-rays and controlling pandemic spread. The deep learning model Faster-RCNN with ResNet-101 trained on the X-Ray and CT-scan data set images for detecting COVID. The dataset was downloaded from the online platform. In the study Paganelli et al. (2022), This paper goes into great length on an Internet of Things-based conceptual architecture for a COVID-19 patient monitoring system. The solution includes a reliable and widely used early-warning score approach for examining and monitoring hospitalised patients, as well as a mechanism for modifying this assessment method to assure assessment individualization. Furthermore, IoT-based remote monitoring systems confront several obstacles, and this paper examined how system characteristics may increase scalability, interoperability, network dynamics, context discovery, dependability, and privacy. The article Poongodi et al. (2021) proposed IoT architecture for robust health system that strengthen COVID-19 administration using binomial point procedure or binary method with the help of simulated people data. This paper feature contact tracing through IoT devices, infection graph visualization, and access wearable device patient data. In the study Kallel et al. (2021), proposed COVID monitoring system using IoT fog cloud based architecture using BPMN 2.0 method using IoT object and storage data.

### 3 COVICT: a proposed IoT based architecture for COVID-19 detection and contact tracing

The proposed COVICT framework for detection and contact tracing of potential COVID-19 cases to suppress the spread of virus is discussed in detail in this section. This state of the art architecture can also be used to predict the contaminated areas for imposition of Smart Lockdown according to CDC guidelines. In this architecture, we assume that each person is equipped with different IoT devices like smart phones and smart watches. The framework of our architecture is shown in Fig. 3.

It consists of eight main parts namely Data Collection and Uploading, Data Center for Symptoms Analysis, Cloud Database, Healthcare Center, Quarantine/Isolation Center, Contact Tracing of positive cases, National Command and Control Center and Industry. For better understanding the said parts are classified according to three phases of COVID-19.

#### 3.1 Diagnosis phase

Early diagnosis is an ultimate solution of winning the battle against COVID-19. Timely diagnosis allows the authorities to save the lives by curbing the virus from wide spread. The following parts of COVICT framework play their part in Diagnosis phase.

#### 3.1.1 Real-time symptom data uploading

The purpose of this part is to sense and collect symptoms of its owner. According to the study carried out by WHO in collaboration with Chinese medical experts, out of the 55,924 confirmed COVID-19 cases, majority of them exhibit symptoms like fever, dry cough, fatigue and flu-like symptoms. While a few of them exhibit symptoms such as headache, sore-throat, shortness of breath, nasal congestion and nausea Chamola et al. (2020).
The said symptoms can be detected by different biosensors fitted in wearable devices and data obtained from on-board sensors of Smartphones like cameras, microphones and inertial sensors. For example sensors based on temperature can detect fever, heart-rate sensors can detect fatigue, sensors based on oxygen can be used for detecting shortness of breath and image-based classification can be used to detect sore throat Otoom et al. (2020). Similarly smartphone’s microphone can be used to detect cough, inertial sensors and camera images can be used to predict headache level. Finally nausea can be predicted using smartphone video Nguyen (2020).

Studies from Stanford University and Mount Sinai Health System show that smartwatches like Apple Watch, Fitbit and Garmin watches can help in prediction of coronavirus infection up to seven days before an individual exhibit virus symptoms. According to studies, variation in heartbeat of a person due to inflammation development due to COVID can predict early infection Smartwatches (2021).

Other important and relevant data like Travel and contact history of the past 21 days, visit to a large gathering and public places and use of protective masks and sanitizers can be uploaded via smartphone apps Otoom et al. (2020).

The collected real-time symptoms and other relevant data is then sent to the data center for analysis. This process is performed by the following main components.

a) IoT Sensor Layer
In the case of COVID-19, Internet of things plays a vital role in fighting and reducing the spread of the virus. In this case study, we focus on different IoT layers; in which the first layer is the sensor hardware layer. This layer consists of all the wearable sensors or in-built sensors in Smartphone which is used for gathering real-time COVID-19 patient data. The sensor layer or the IoT device layer transmits data to the internet gateway layer.

b) Internet Gateway
The internet gateway layer is a node or router in the network which connects the sensor layer with the outside internet layer. It acts as a medium between sensor layer and the edge device. It helps to connect all the COVID-19 patient sensors with the internet and transmits all the sensors data collected from COVID-19 patient to the outside world.

c) Edge Device
It is the hardware or device which controls the flow of COVID-19 patient’s data between different networks and cloud database. It is responsible for COVID-19 patient data optimization, data buffering and real time data processing.

3.1.2 Cloud database
The data collected through wearable and hand held device is uploaded to the cloud database via Smartphone or wearable devices. The cloud infrastructure transfers the data received to data center for analysis and communicates the processed results to remote health physician in healthcare center for further clinical investigation. Cloud database is also used for the storage of data. This database consists of all patients data which was gathered from Healthcare centers/hospitals and Quarantine/isolation centers.

3.1.3 Data center for symptoms analysis
Data collected from the sensor infrastructure is required by the authorities for better management of a pandemic. The combine use of IoT, artificial intelligence and machine learning algorithms efficiently analyze and process sensed data which is utilized by different organizations, industries, academia, aviation, healthcare centers/hospitals and quarantine/isolation centers. The data center process the data and predicts the potential cases of COVID-19, manage supply of goods and identify COVID-19 hot spots for imposing smart lockdown.

3.1.4 Healthcare center
The processed data of suspected patients of COVID-19 is transferred to the remote health physician in healthcare center / hospital for further investigation required for confirmation of the disease. Based on the investigation, patient is advised for isolation to prevent further transmission. After confirmation of a positive case, the healthcare authorities track the location of patient to mitigate the spread of the virus with the help of travel history of a patient uploaded to the Data center.

The healthcare authorities monitor the health of patient remotely through the data collected by the IoT based wearable and hand-held devices.

3.2 Quarantining and contact tracing phase
The quarantine of an individual is to sustain his activities or to separate the persons who are in real not ill but may be exposed to viral infection. Quarantine is the most effective solution to curb the virus spread and to keep the wheel of life moving. After detection of suspected cases by the health authorities, it is very important to isolate / quarantine the infected people at quarantine centers or hospitals to curb the spread of virus.

As stated above, contact tracing is our decisive weapon in this war against COVID-19. Effective contact tracing halts the transmission from spreading further. The second phase of COVID-19 is implemented by following parts of our architecture.
3.2.1 Quarantine center

The purpose of this component of our COVICT framework is to maintain data records of people in quarantine or isolation center. These records comprise of technical (or health) and non-technical data such as person’s age, gender, symptoms, chronic ailments, history of family diseases, travel history and close contacts details during the incubation period of the virus. The recorded data would contribute in assessing the trends in COVID-19 clinical characteristics thus optimizing responses of public health. Treatment reactions for each individual would also be recorded that would help in understanding the behavior of the virus by analyzing the relevant recorded data.

3.2.2 Contact tracing

Contact tracing, as mentioned above, is a process of identifying all people that have come in contact with a COVID-19 patient during the past two weeks. While tracing contacts it must be ensured that important elements of privacy are not compromised. The key is thus building a framework in which privacy and sharing of data can both exist in a manner that add responses to health of people. The main aim of developing COVICT is, therefore, to design a system that would be acceptable to masses in terms of security and privacy.

In this study, we have proposed a semi-automated contact tracing technique. The technique is termed as semi-automated because contacts’ data will remain in the smart phone of users thus preserving the user’s privacy. The data can be retrieved on the permission of the user.

In our proposed scheme, contact tracing is performed by using device-to-device (D2D) communication. In D2D peers can be discovered on the basis of several social attributes Jameel et al. (2018) (proximity and contact duration in our case). The main advantage of using D2D based contact tracing comes from secrecy and privacy because contacts information is not saved at the central database Haus et al. (2017).

As per Polymod study, a contact is defined as a duplex conversation of at least three or more words physically or having a physical contact with other persons. A contact at high-risk is the one that has a physical contact, at least 15 or more minutes long or that occurs regularly Mossong et al. (2008). Secondly, as per CDC guidelines safe distance criteria for COVID-19 transmission is 6 feet.

We will set these aforementioned criteria for peer discovery in our scheme. This implies that owner can establish D2D communication link with only those people who violate this above mentioned criteria.

The process flow of contact tracing to reduce the further virus spread has been depicted in Fig. 2. Once health authorities get confirmation through different clinical investigations about the infected person, they will request the data stored in his mobile about the close contacts made during the last 21 days. Travel History of patients can further narrow the contact tracing. This short listing is necessary due to the scarcity of testing kits. The authorities will inform the

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Fig. 2 Process flow diagram of contacts tracing
| Sno | Ref | Aim | Technique | Dataset | Key feature |
|-----|-----|-----|-----------|---------|-------------|
| 1   | Kolhar et al. (2020) | Proposed IoT based framework for cities with lockdown | CNN | FFDB and WIDER FACE | Three-layered edge computing architecture |
| 2   | Angurala et al. (2020) | Proposed IoT assisted Drone Based Covid-19 Medical Service (DBCMS) framework | Clustering | Covid-19 disease | Three layered Drone Based Covid-19 Medical Service (DBCMS) |
| 3   | Liang et al. (2020) | Proposed interoperable Internet of COVID-19 Things (IoCT) architecture | YOLOv3, CNN | Image Data | Real-time situational awareness system design and development, Person to key risk assessment for indoor COVID-19 through open geo spatial standards. |
| 4   | Aman et al. (2021) | Paper highlights the IoMT architecture, applications, technologies, and security developments | Predictive Model, Data Mining & Analytics, Decision Making, System Classification | Survey data | Blockchain to lessen security threats to humans and systems, Discussed the research and role of AI in IoMT |
| 5   | Ahmed et al. (2020a) | Proposed an IoT based deep learning framework for early corona virus assessment | Faster-RCNN, ResNet-101 & RPN | X-Ray and CT scan images | The framework is capable of assisting medical experts or radiologists, relieve the working pressure, and might help in the control of pandemic. Moreover, deep learning models are used in COVID detection. |
| 6   | Paganelli et al. (2022) | Proposed an architecture for remote health monitoring for COVID patient which address interoperability, network dynamics, context discovery, reliability and privacy | Deal with data flows using health care cloud | Patient sensor data | Flexibility and configuration with health care, efficient way of handling medical data, Data API integration, Devices energy optimization, & comprehensive overview. |
| 7   | Poongodi et al. (2021) | Proposed IoT architecture for robust health system that strengthen COVID-19 administration | Binomial point procedure or binary method | Simulated people data | Contact tracing through IoT devices, Infection graph visualization, Access wearable device patient data |
| 8   | Kallel et al. (2021) | Proposed COVID monitoring system using IoT fog cloud based architecture | BPMN 2.0 | IoT object and storage data | IoT architecture supports distributed inter and intra layer communication, Model corona virus monitoring system |
| 9   | Proposed Work | Proposed COVICT: An IoT based architecture for COVID-19 detection and contact tracing with the application of machine learning | Logistic Regression, Random Forest Classifier, Gradient Boosting Classifier | Patient symptoms data | Diagnosis based on real-time symptoms data collection, Semi-automatic contact tracing, data analysis and analytics through machine learning, isolation management, the outbreak, response management, industrial management, and supply chain management |
persons about the risk and will advise them about implementation of self-isolation.

### 3.3 After recovery phase

Social distancing is being regarded as best technique of defense against the current pandemic. However, to implement effective social distancing, governments around the globe impose mandatory lock downs. The strict and effective implementation of lockdown require daily needs of the public to be addressed at their homes. People from different industrial sectors, health authorities and government authorities need to collaborate with one another to get the fruitful results of lockdown. NCOC center and Industry components of our COVICT framework complete the third phase of COVID-19.

#### 3.3.1 National command and control (NCOC) center

The purpose of this component of our COVICT architecture is to monitor the spread of the virus based on the data provided by the Data Center. The Governing authorities will take the feedback from NCOC center and will make decisions like Smart lockdown, Supply chain management, Gradual and safe reopening of economic sectors, etc.

According to CDC guidelines lockdown will be imposed in the areas where 10 percent of total population is infected with the virus so that transmission of virus can be halted.

### Table 3  Comparison of literature review on the basis of IoT based frameworks

| References                        | Author            | Infection diagnosis based on symptoms | Prediction of travel history | Contact tracing | Smart lockdown | Simulation |
|-----------------------------------|-------------------|---------------------------------------|------------------------------|-----------------|----------------|------------|
| Siriwardhana et al. (2020)        | Yushan et al.     | ✓                                     | x                            | ✓               | x              | ✓          |
| The coronavirus pandemic (2021)  | SORMAS            | ✓                                     | ✓                            | ✓               | ✓              | ✓          |
| Nasajpour et al. (2020)           | Muhammad et al.   | ✓                                     | x                            | x               | x              | ✓          |
| Nguyen (2020)                     | Thanh et al.      | ✓                                     | ✓                            | ✓               | x              | ✓          |
| Chamola et al. (2020)             | Vinay et al.      | ✓                                     | ✓                            | ✓               | X              | ✓          |
| Otoom et al. (2020)               | Mwaffaq et al.    | ✓                                     | ✓                            | ✓               | ✓              | ✓          |
| Hu (2020)                         | Peng et al.       | ✓                                     | x                            | ✓               | ✓              | ✓          |
| Roy et al. (2020)                 | Abishek et al.    | ✓                                     | ✓                            | ✓               | ✓              | ✓          |
| Kretzschmar et al. (2020)         | Mirjam et al.     | x                                     | x                            | ✓               | x              | ✓          |
| Dar et al. (2020)                 | Aaqib et al.      | x                                     | x                            | ✓               | ✓              | ✓          |
| Ahmed et al. (2020b)              | Nadeem et al.     | ✓                                     | x                            | x               | ✓              | ✓          |
| Braithwaite et al. (2020)         | Isobel et al.     | ✓                                     | x                            | ✓               | ✓              | ✓          |

**Proposed COVICT Architecture**

![Proposed IoT architecture for COVID with AI applications](image)
under developed countries, complete lockdown can further deteriorate the economy. Therefore concept of smart lockdown has been introduced. Based on the data collected about the location of the clusters of infected persons, NCOC center proposes smart lockdown in the infected streets, schools, industries or offices according to the criteria set by CDC.

NCOC center is also responsible for managing supply of PPEs, sanitizers, face masks, Testing kits, ventilators and other day-to-day items. The estimation of supply is made on the basis of data (number of positive cases, people in quarantine / isolation and hospitals) provided by the Data Center for analysis. NCOC center suggests the manufacturing industries for the continuous supply of the required material. Keeping in view the limited manpower at the industries, continuous monitoring is required to maintain the supply of items.

Due to the restrictions enforced by the authorities to mitigate the spread of the virus; economic sectors and industries are badly effected. The industries are cautiously reopening after months of restrictions. In this phase everyone needs extra precaution. Restricting physical contacts by limiting manpower and social distancing needs to be enforced to mitigate the spread of the virus. NCOC center proposes SOPs for different sectors such as Hotels, Academia, Games, Shopping Centers, Aviation and Factories for gradual reopening based on the AI application of risk prediction.

3.3.2 Industry

Due to the scarce treatment strategies, social distancing is regarded as the decisive technique against this pandemic. However, to implement social distancing effectively, governments around the globe have imposed lockdowns causing huge impact on global economy. Industrial sectors are facing discontinuation in the supply chain of day-to-day items. Most of the people around the globe are not familiar with living under these restricted conditions. For strict lockdown imposition, public essential requirements need to be addressed at home. Different industries require to collaborate with the government sector for implementation of effective lockdown.

One possible AI application against the pandemic is risk prediction. Industrial sectors such as academia, factories, aviation, hotels, markets, Olympics games, etc will assess the risk predicted by AI and ML algorithms processing in the Data Analysis Center and will restart their operations with safe distance SOPs as proposed by NCOC center.

The reopening of industrial sectors such as schools, workplaces, etc require precautionary techniques to keep each individual safe from COVID-19 virus. Early identification of infected persons and social distancing need to be kept in mind for reopening safely. IoT based wearable devices such as Smart bands, Smart cards and Smartphones can be used for early diagnosis and safe distance implementation.

3.4 Insightful & practical implications of approach

COVICT is an IoT-based COVID-19 detection, monitoring and semi-automatic contact tracing system that we have proposed for early identification and monitoring of new cases of COVID-19, and managing response to the outbreak at the same time. COVICT is a system that allows healthcare authorities to validate new cases and control the transmission of disease. As a multifunctional system, it can also be used for surveillance of cases, isolation management, supply chain management and tracing of close contacts to minimize the spread of the virus.

The IoT-based COVICT approach with the application for artificial intelligence consists of multiple phases such as the diagnosis phase, quarantining & contact tracing, and after recovery phase. If the government directly lockdown everything it will affect the nation’s economy, increase unemployment, reduce industrial productivity, increase the inflation rate, the burden on the public health system and pandemic influence on Gross Domestic Product (GDP). Therefore, in this study, we came up with an IoT & AI-based smart solution for lockdown and contact tracing as shown in Fig 3. The proposed architecture can be practically implemented by connecting all the related organizations such as data analysis centres, government authorities industries, quarantine centres and data cloud centres. Practically all these departments exist in real and can be compared for example “Federal Statistical Research Data Centers” like data analysis centre, government authorities as “World Health Organization”, COVID database as “Centers of Disease Control & Prevention” and industries such as aviation, pharmaceutical, automobile and IT.

All phases have the process flow of our proposed COVICT framework can be explained as under

- Real-time symptoms data is collected by the sensors in the wearable band or Smartphone. The collected symptoms are uploaded to the data analysis center.
- The Data analysis center receives symptoms data through cloud infrastructure. The data received is processed by different machine learning algorithms to detect potential COVID-19 cases.
- After detecting the potential cases, the data is sent to remote health physician for further clinical investigations for identification of positive cases.
- Once confirmed, the patients are quarantined and isolated in hospitals or isolation centers. The patient is asked to provide the data of the D2D peers stored in the owners phone. The close contacts as per the history of areas
traveled during the last three weeks are then contacted for risk alert and self isolation.

- Based on the location of clusters of infected persons, NCOC Center suggests implementation of smart lock-down in the contaminated areas to curb the further spread of virus
- NCOC center will manage supply of PPEs, testing kits and other day-to-day material based on the data provided by Data Center.
- NCOC center will suggest SOPs for safe distance after gradual reopening of different industrial sectors.

### 4 Results and discussion

#### 4.1 Dataset

The dataset downloaded from the online source kaggle. It consist of 21 features including dependent and independent features. Furthermore, It has 5,434 number of instances. All the research executed or run on the laptop with intel i5-6300HQ 2.3 GHz processor, 12 GB DDR4 RAM, NVIDIA GeForce GTX 960M graphic card.

In Table 4 the features or attributes that are used in this study are listed.

| SNo | Attributes                          |
|-----|------------------------------------|
| 1   | Having problem in breathing        |
| 2   | High fever                         |
| 3   | Dry cough                          |
| 4   | Sore throat                        |
| 5   | Nasal congestion                   |
| 6   | History of asthma                  |
| 7   | Chronic lung disease               |
| 8   | Severe headache                    |
| 9   | Heart disease                      |
| 10  | Family history of diabetes         |
| 11  | Hyper tension                      |
| 12  | Symptoms of fatigue                |
| 13  | Gastrointestinal                   |
| 14  | Abroad travel history              |
| 15  | COVID patient contacts             |
| 16  | Large gathering participation in last 14 days |
| 17  | Expose of public places visiting   |
| 18  | Expose of family working in public places |
| 19  | Masks wearing                      |
| 20  | Sanitizing process in markets      |
| 21  | COVID-19 history                   |

#### 4.2 Data preprocessing

In this study, the features only have two categorical values that are “Yes” and “No” therefore, the categorical data encoded into numeric form. With the help of numeric data the correlation analysis is performed on the data set and the heatmap is developed in python software environment as shown in Fig. 4. The pandas and seaborn library is used in data preprocessing and heatmap development. The “wearing Masks” and “Sanitization from market” values are the same i.e. “No” through out data therefore, both features are vacant and showing no values in heatmap.

#### 4.3 Machine learning models results

In this study, we have used different machine learning algorithms such as logistic regression, decision tree, random forest and gradient boosting for the prediction of COVID Contact tracing feature. All the algorithms are developed for the same dataset and compared. In this study, rapid minor software is used for the model data preprocessing, model development, visualization and tabular comparison.

##### 4.3.1 Logistic regression

The process of the logistics regression has been exploited in broad applications addressed with machine learning for big data analysis. The Fig. 5 shows the region of convergence or lift chart of the logistic regression bar plot. In Table 5 the performance of model is discussed where the model is evaluated using different model evaluation methods and follow different criteria such as accuracy, classification error, AUC, model precision, recall, F_measure, sensitivity and specificity. The logistic regression model accuracy is 64.4%, classification_error is 35.6%, AUC is 72.3% , model precision is 63.5%, recall is 69.5%, F_measure is 66.3% , model sensitivity is 69.5% and specificity is 59.2%. The logistic regression model is the most basic algorithm and used for classification. The accuracy of it is not good as compare to other models that are used in this study. One can use logistic regression method for just to get an idea how the system perform as it requires very less computational power and training time.

##### 4.3.2 Random forest classifier

Random Forest (RF) is a most famous and important algorithm attached with supervised classification topology. The reason RF mostly used in research is because of it’s accuracy and robustness. RF has effectively applied to different ML applications such as medical, aerospace, and bio-informatics etc. RF method consist of decision trees and the tree nodes is evaluated through two parameters,
The RF classifier works on combining various tree classifiers. The individual tree classifier is based upon a random vector which is independently sampled through the input vector, and each tree casts a unit vote for classification of inputs data. The random forest classifier used for this study consists of using the number of tree in the forest and the number of features that are randomly selected.
randomly selected features or a combination of features at each node to grow a tree. The random forest Classifier model lift chart shown in Fig. 6. The confusion matrix of random forest classifier is shown in Table 6. The prediction of No class precision is 91.96%, and class precision of Yes is 98.79%. The true No class recall percentage is 95.02% and true Yes class percentage is 98.00%. The random forest classifier performance shown in Table 7, the model accuracy is 0.97422, classification error is 0.02577, AUC is 0.97166, precision is 0.987980, recall is 0.9800, F_measure is 0.9839, sensitivity is 0.9800 and specificity is 0.950054. The standard deviation of each criteria is also shown in the Table 8.

### 4.3.3 Gradient boosting

GBDT is a gradient boosting algorithm that utilizes decision stumps or regression tress as weak classifiers. In GBDT, the weak learners measure the error observed in each node, split the node using a test function. The lift chart of GB are shown in Fig. 7. The performance of GB is shown Table 9.

#### Table 6 Confusion matrix of random forest model

|                | true No | true Yes | class precision |
|----------------|---------|----------|-----------------|
| Pred. No       | 658     | 191      | 77.50%          |
| Pred. Yes      | 118     | 585      | 83.21%          |
| Class recall   | 84.79%  | 75.39%   |                 |

#### Table 7 Random forest model performance

| Criterion             | Values |
|-----------------------|--------|
| Accuracy              | 80.1%  |
| Classification_error  | 19.9%  |
| AUC                   | 89.6%  |
| Precision             | 83.2%  |
| Recall                | 75.5%  |
| F_measure             | 79.1%  |
| Sensitivity           | 75.5%  |
| Specificity           | 84.8%  |

#### Table 8 Confusion matrix of logistic regression

|                | True No | True Yes | Class precision |
|----------------|---------|----------|-----------------|
| Pred. No       | 454     | 240      | 65.42%          |
| Pred. Yes      | 313     | 545      | 63.52%          |
| Class recall   | 59.19%  | 69.43%   |                 |

#### Table 9 Gradient boosting performance

| Criterion             | Values |
|-----------------------|--------|
| Accuracy              | 97.1%  |
| Classification_error  | 2.9%   |
| AUC                   | 99.3%  |
| Precision             | 97.7%  |
| Recall                | 96.5%  |
| F_measure             | 97.1%  |
| Sensitivity           | 96.5%  |
| Specificity           | 97.7%  |
is 97.7%. The confusion matrix of gradient boosting shown in Table 10 shows that the performance of it is far better than random forest and logistic regression.

In this study, we have used logistic regression, random forest classification and gradient boosting methods for the classification and prediction of contact with COVID patient which is the dependent variable in this research. The research shows that gradient boosting algorithm perform best among all other algorithms.

5 Challenges

In this section we address challenges that will arise in the implementation of any IoT-based framework. Suggestions for addressing these challenges is also discussed.

5.1 Security and privacy

A recorded interview with remote healthcare physician for further clinical investigation may contain private information that could only be shared with medical physicians. Similarly, contact tracing applications collect sensitive information such as user’s location data and close contacts without user’s knowledge. Sharing of this sensitive user data with third-party advertisers pose a serious privacy threat. In addition, IoT based frameworks increases security risks as these low-end devices can be easily hacked and are quite vulnerable to Denial of Service attacks. This challenge can be addressed by developing privacy preserving protocols for video calls and contact tracing. These protocols should be capable of utilizing minimal sensitive data. Similarly new security techniques must be deployed that are both scalable and lightweight to secure IoTs. Transmission of encrypted data and solutions based on distributed security mechanisms can prevent attacks and protect sensitive collected data.

5.2 Scalability

In the recent years new applications such as 5G Cellular services, UAVs based services, online platforms for education and businesses and tele-medicine have been rapidly deployed. These services have increased the network traffic by many folds and can cause increased network congestion. Moreover, management of billion of IoTs will be quite challenging. The network should be therefore scalable to address the increased number of events causing traffic. Network Slicing is a promising solution to cope with this scalability issue. NS is capable of dividing physical network into number of logical networks that can be dedicated to individual applications for their respective use. Thus NS can result in significantly increased scalability.

5.3 Latency

One of the most critical challenge linked with real-time COVID-19 symptoms data collection is high latency. Since data collected through wearable devices are uploaded to cloud database that are located far away from the users in terms of network topology, high latency is introduced.

To address the problem of latency, the most feasible solution is to move the cloud services in the proximity of the user i.e. at one hop. This is called Mobile Edge Computing. MEC is a special case of cloud computing in which computing/storage capabilities are brought near the users. Hence, MEC offers very low latency and jitter as compared to cloud computing.

6 Limitations and future recommendations

In this section we will address limitations of our research work and future recommendations to improve the proposed COVICT platform.

6.1 Limitations

COVICT can be very beneficial in limiting the spread of the virus. However, there are some limitations to address before its large-scale implementation. Some weaknesses of COVICT are discussed as follows:

- Data Privacy: COVICT is a real-time IoT based system for detection of COVID-19 patients. The breach of sensitive information regarding health of patients and sensor data interference can counter the overall benefits of the proposed system.
- Failure Risks: Failure in the system hardware or network dis-connectivity can compromise the performance of connected devices and sensors causing remote healthcare activities at risk.
- Accuracy: Real-time handling of such massive data can effect the reliability and accuracy of COVICT.
- Cost: While COVICT promises cost reduction in detection and monitoring of COVID-19 patients, the cost of its installation, maintenance and training will be little high.

| Table 10 | Confusion matrix of gradient boosting model |
|-----------|-------------------------------------------|
|           | True no | True yes | Class precision |
| pred. No  | 759     | 27       | 96.56%          |
| Pred. Yes | 18      | 748      | 97.65%          |
| Class recall | 97.68% | 96.52% |
6.2 Future recommendations

The future recommendations to improve COVICT architecture for real-time detection and contact tracing to contain COVID-19 are discussed as follows:

- It is recommended to develop privacy preserving protocols for video calls and uploading sensitive data for contact tracing. These protocols should utilize minimal sensitive data.
- It is recommended to utilize the cloud services in the vicinity of the user i.e. at one hop to address the latency, jittering and network dis-connectivity issues.
- It is recommended to bring innovative solutions to cope with the scalability issue. Network Slicing is a promising solution that increase scalability of the system by dividing physical network into number of logical networks for multiple applications.

7 Conclusion

In this paper, a new approach for contact tracing has been proposed based on IoT architecture. It has been shown that contact tracing using D2D is more reliable and with the travel history prediction, the tracing will be even more effective. Moreover, prediction of travel history can be used to track clusters of infected persons for imposing smart lockdown.

While our world is struggling hard for more than two years to survive the devastation caused by COVID-19 pandemic, appreciable efforts have been shown by emerging technologies namely Artificial Intelligence, IoT and 5G in keeping our hopes alive. The main issue is to efficiently detect the COVID-19 cases. In this context, we have proposed an IoT-based COVICT architecture so that the healthcare authorities shall be able to detect potential COVID-19 cases and can perform contact tracing with the help of machine learning models. The machine learning model helps in the prediction and estimation while IoT framework work as the medium between all the organizations and sectors.

It is the need of time that world should shift towards using smart procedures for contact tracing and imposing smart lockdowns to control this pandemic. The countries already using smart solutions during first and second wave Chimmula and Zhang (2020) have effectively controlled the wide spread of disease. The proposed COVICT architecture will act as fundamental block for COVID-19 detection and contact tracing along with providing directions to impose smart lockdown in infected areas. Our proposed architecture can effectively detect and provide guidance to quarantine and health centers for active measures. The architecture can be easily adopted due to D2D communication hence security of public data can be ensured. By having extensive literature, our proposed architecture theoretically covers all the aspects to stop the widespread of COVID-19 and the actions needed by data analysis and isolation centers.

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