Feature Article: Healthcare Technology

Preventing COVID-19 Spread Using Information and Communication Technology

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***Abstract*—Without an effective vaccine, treatment, or therapy, the Coronavirus Disease 2019 (COVID-19) is spreading like fire and claiming lives. Countries began to adopt various strategies such as lockdown, mass testing, tracing, quarantine, sanitization, isolation, and treatment to contain COVID-19. However, it was soon realized that we need to take the help of powerful technologies to combat the spread of deadly COVID-19 until a vaccine or a drug is discovered. In this article, we discuss how the use of cutting edge technologies such as the Internet of Things (IoT), Big data, artificial intelligence (AI), unmanned aerial vehicles (UAVs)/drones, blockchain, robotics, autonomous ground vehicles, communication technologies in screening, testing, contact tracing, spread analysis, sanitization, and protocol enforcements can help prevent the COVID-19 spread.**

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THE CORONAVIRUS DISEASE 2019 (COVID-19), which is now a global pandemic, caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). After being initially reported in Wuhan Province, China, in late 2019,

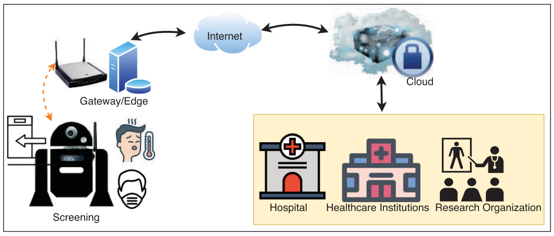

Figure 1. Technology-driven COVID-19 screening.

it is spreading like wildfire and already marked its presence in 213 countries and independent territories around the world. COVID-19 is highly contagious and has high transmissibility via direct person-to-person, airborne, and indirect transmissions. COVID-19 is highly contagious and has high transmissibility via direct person-to-person,[1] airborne,[2] and indirect transmissions.[3] As of July 26, 2020, a total of 16 235 924 confirmed cases and 649 153 deaths have been reported.[4]

Since no effective antiviral drugs or vaccines available, containment and prevention are the cornerstones of managing the pandemic. It has been noticed that technologies are playing a significant role in countries like Singapore and South Korea for pandemic management, and facilitating effective strategy and response, which was difficult to achieve with manual works and management.

In this article, we discuss the potential application of interrelated and cutting edge technologies such as IoT, artificial intelligence (AI), UAVs/drones, robots, blockchain in strategies adopted for preventing the COVID-19 spread: (1) Screening; (2) Testing; (3) Contact Tracing; (4) Spread Analysis and Prediction; (5) Sanitization; (6) Lockdown, Quarantine, and Self-Isolation.

SCREENING

Currently, in countries like India, Brazil, Bangladesh, Mexico, Indonesia, infrared forehead thermometers are used in public places for thermal screening. However, this manual screening mode is prone to errors and has the risk of cross-contamination of COVID-19. Another big issue is, it does not scale for large crowd and population. Thus, we need to have technology-enabled automated (does not involve human) mass screening mechanism that can perform a quick, touch-less screening to measure the temperature, analyze heart rate, respiratory rate, etc., with high accuracy. Such screenings can help in the detection of key vital signs, the infection risk level, and raise alarms to assist people and for action to minimize the risk for spread. Along with the scanning and screening of health parameters, more features can be integrated to check whether imposed social distancing norms are being followed are not, such as wearing mask, face-shield, maintaining proper distance, etc.

The generic view of automated screening using robot is shown in Figure 1. The key technology enablers for the screening process of COVID-19 are as follows.

1) *Sensors and IoT:* Cameras (thermal/visible), thermal sensors, four-dimensional (4-D) imaging sensor, RF sensors, etc., to capture the health parameters, activities, and objects. IoT is also being experimented in the form of wristbands (wearable) that can measure the heart rate, body temperature, and blood pressure to monitor early COVID-19 symptoms. The data recorded are uploaded to the cloud for analysis, similarly, a thermal imaging helmet, and AR glasses with connectivity features, and Smart thermometer, Thermal imaging drones are also being used to do mass screening.
2) *Robotics:* The powerful sensors mentioned above are mounted over autonomous/remotely operated mobile robots and deployed in public areas like hospitals, airports, railway stations, factories, shopping malls, movie halls, hotels, offices, borders (district, state, country), and so on for screening multiple people simultaneously. It can also be deployed in the home, building, and societies to repeatedly screen in/out people. Autonomous robots, collaborative robots, social robots, etc., can be utilized for the same. Most of the processing can be done locally on robots itself or local servers (at the edge) using powerful algorithms. Moreover, cloud services can also be utilized when the need arises for processing and storage.
3) *Bluetooth, Wi-Fi, Cellular*: Fronthaul wireless connectivity using radio access technologies (RATs) such as Bluetooth, Wi-Fi (IEEE 802.11 g/n/ac), and cellular (4G/5G) plays a crucial role in deploying mobile robots anywhere and

anytime. The data or results collected from robot sensors can be uploaded to edge, fog, and cloud via backhaul for storage, processing, and analysis, which can be utilized by the concerned authorities such as hospitals, research organizations, and healthcare and government institutions. Thus, the network allows to upload/download, link entities, monitor, and control the screening process remotely.

4) *AI and machine learning (ML)*: AI and ML can offer great help in the screening process. For instance neural networks (NN) specialized models can help in identifying specific patterns within images and data correlation models.[5] The multimodal data captured by the robot sensors are parsed and preprocessed. Then, it can be given to AI-powered models for vision, object detection, facial and speech recognition, activity detection, etc., to validate various social-distancing norms and test health parameters.
5) *Blockchain*: Blockchain is widely being explored for e-Healthcare systems[6] and has been considered as one of the potential candidates for recording healthcare data securely. The blockchain can be used to record some critical transactions of screening processes such as suspected cases and people not following social-distancing norms. These secure and transparent records on the blockchain can help authorities to assist people and take necessary actions. The blockchain deployment strategies such as public or private can be decided by the administration. A suitable consensus mechanism can also be decided depending on the complexity, security, and privacy requirements.

Using these technology-driven autonomous or remotely operated robots for the screening process can increase the accuracy, efficiency, and coverage, reduce human-to-human contact and lower the risk of infection.

TESTING

Currently, most countries recommend collecting nasopharyngeal and oropharyngeal swabs for initial diagnostic testing for COVID-19. This diagnostic process involves collecting samples, handling and transferring samples, and finally, testing. However, the entire procedure is performed manually, which is not considered to be appropriate due to the following main factors: (1) Require personal visits to a hospital, clinic, laboratory, or mobile lab. These visits pose risks and expose more people to COVID-19. (2) Lack of well-trained and qualified staff to collect the swab, handle it, and process test samples. (3) The considerable turnaround time of the test process. (4) The medical staff (with limited protective gear) are at serious risk of infection.

How the available technologies in forms of robotics, drones, AI/Ml, and Blockchain can address COVID-19 testing process-related issues are summarized as follows.

1) *Robots for sample collection*: Now, a throat and nasal swabbing robots are being developed that can take throat and nasal swabs from suspected patients.[7] These autonomous robots use cobot arms and an end-effector. The vision system helps the robot identify the right points to swab in the patient's nasal and throat. Once the swab is collected, the robot arm places the sample in a box or jar and close the lid, then transfer it to a lab for analysis.
2) *Autonomous drones or autonomous ground vehicles for sample transfer to lab*: The drones and autonomous ground vehicles can be used to transfer samples from the collection point to the lab for testing.
3) *Robots for COVID-19 sample preparation*: The robot, called flowbot ONE, a Danish pipetting robot helps is automating COVID-19 testing processes. This robot takes the charge right after inoculation and automates the entire task of preparing samples (mixing liquids and chemicals) for COVID-19 analysis.[8]
4) *Blockchain to record the test details*: The blockchain-based COVID-19 healthcare records can be adapted to store all the testing details securely. Once recorded after the consensus, the details will be immutable and can be accessed by authenticated entities only. Concerned authorized agencies can use these records for further analysis and action. The blockchain can ensure that the test detail records are tamper resistance due to its irreversibility and immutability properties.

Blockchain is in the development phase, and it is not a complete strategy for COVID-19. There are

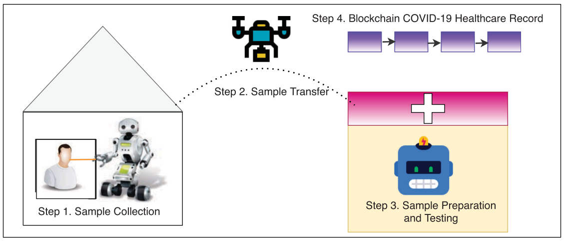

Figure 2. Technology-driven COVID-19 testing.

some technical impediments such as privacy concern, authentication, authorization, accessibility control, inefficient performance, energy consumption, etc., which must be taken into account prior to its deployment for COVID-19 prevention stages, for example, ensuring the anonymity and unlikability for privacy of COVID-19 patients using cryptographic techniques (pseudonym authentication, proxy re-encryption), authorization by leveraging smart contract and attribute-based access control mechanisms, authentication using multifactor authentication and digital signature, etc.

5) *AI/ML for preliminary diagnosis for COVID-19*: Various efforts have been made to use AI/ML for developing a novel COVID-19 diagnostic approach. For example, recently, ML algorithms have been used for diagnosis of COVID-19 infection from either X-Ray or CT Scan images. AI has also been used in preliminary diagnosis of COVID-19 from the cough sample.[9] The smartphone embedded sensors have been proposed to diagnose COVID-19 with the help of AI-enabled framework.

The technology-enabled automated COVID-19 testing process (sample collection, transfer, testing) minimizes the mistakes and potential human errors, minimizes the turnaround time, reduces the risk of spread and contagion of COVID-19 in the process, lowers the stress level, and relieve medical and lab staff from a task of a high risk of exposure. It can improve the scale and speed of the COVID-19 testing process. The generic view of the technology-driven COVID-19 testing process is shown in Figure 2.

CONTACT TRACING

Contact tracing is considered to be an important public health measure to control the COVID-19 spread. It is an essential component of comprehensive strategies to combat COVID-19, which helps identify persons who may have been exposed to a COVID-19 confirmed case(s). The process of tracking those contacts helps in breaking the chain of COVID-19 transmission from human-to-human.

Contact tracing is normally done via a personal interview of the infected persons, which is conducted by the health authorities. Such contact tracing strategies with the help of a trained and dedicated workforce, community engagement and public support, etc., were successful in the early stages of the COVID-19. However, these strategies are no longer effective and feasible due to large-scale community transmission. Some of the significant challenges of contact tracing are (1) inaccurate recall of all contacts leading to incomplete contact tracing; (2) inefficient paper-based tracking systems; (3) delays in the identification of all contacts; (4) complex data management requirements.[10]

Technology is playing a big role in overcoming these challenges of contact tracing. Two such technology-enabled solutions are summarized as follows.

1) *IoT/Smartphone Apps*: These days, smartphones and wearables[11] are equipped with powerful sensors, cameras, GPS, connectivity (Bluetooth, NFC, Wi-Fi, Cellular), and various other advanced technologies, which makes them a perfect device for contact tracing. Since people carry it with them for most of the time, it may help in location tracking, proximity detection, and automatic collection of contact data. Thus, in many countries, various smartphone contact tracing apps have been developed to capitalize on all these features and assist in contact tracing. The system architectures of these apps are classified into three categories[12]: centralized, decentralized, and hybrid. The entire process is divided into four steps: (1) *Registration phase:* Register a user in the architecture by installing the app and accepting the terms and conditions. (2) *Registering contacts information:* When a registered user comes in contact with another registered user (app user), they exchange a message via Bluetooth. (3) *Uploading contacts data:* When an app user is diagnosed positive, contacts records are

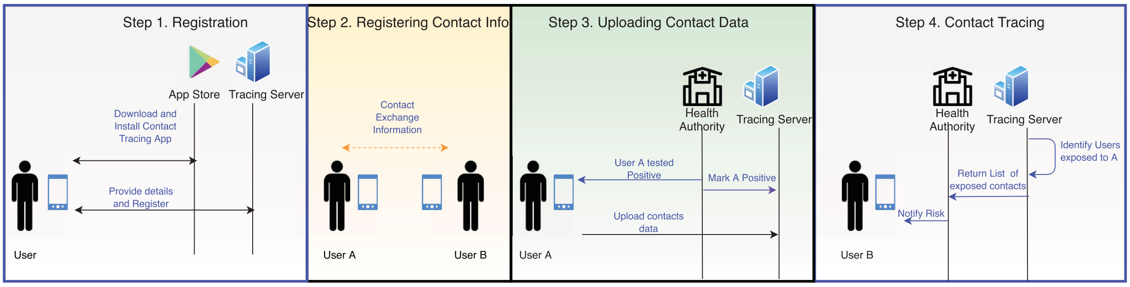

Figure 3. Technology-driven COVID-19 contact tracing.

uploaded to the server for processing depending on the architecture (local processing in case of decentralized). (4) *Contact tracing process:* The records are processed locally or in the cloud, and a list is prepared with relevant information and forwarded to health officials for further actions. Some of the popular apps are: Aarogya Setu, CovidSafe,[13] TraceTogether, SwissCoviD-DP-3 T, PACT, Hamagen, DESIRE, and ContraCorona.

2) *Blockchain*: These apps for contact tracing will be effective only when they are integrated into an health system in a secure manner using a trusted platform. The powerful characteristics of blockchain make it a suitable candidate to address the issues raised related to data management, security, privacy, and efficiency of these smartphone contact tracing apps.

The generic view of the technology-driven COVID-19 contact tracing is shown in Figure 3.

SPREAD ANALYSIS AND PREDICTION

The contract tracing helps to find people who have been exposed and at risk. However, we need to collect data and information to gain better knowledge about the COVID-19 spread, such as about (1) infection source (imported, local); (2) superspreaders; (3) COVID-19 clusters and hotspots; (4) community transmission, affected age group and gender; (5) cases over time (confirmed, active, death, critical). (6) recovery and mortality rate (region wise). (7) symptomatic and asymptotic cases details, etc.

Since COVID-19 has already spread at an alarming rate, manual work or simple data management may not be helpful in collecting all of these data and building detail knowledge about the COVID-19. However, some of the advanced technologies and tools can help us (already helping to some extent) for this purpose, which are summarized as follows.

1) *Data science and AI*: Big data, data science, and AI play a big role in the fight against COVID-19. With the advent of various new techniques and APIs used in data science, we can easily crawl and access tons of COVID-19 data, which can be collected from multiple sources such as news bulletins, data released from government agencies, from social networking websites, crowd-sourced data, etc. These data can be visualized in various forms of charts, graphs, networks, and tables. These visualizations are much simpler, practical, and informative. For example-various dashboards for COVID-19 trackers have been developed and are accessible to easily track regional and global COVID-19 cases over time.[14] The power of AI can be utilized in COVID-19 cluster and hotspot prediction, community transmission prediction, COVID-19 curve prediction, etc.
2) *Advanced analytics*: Some of the popular mechanisms used these days for analysis, such as graph, path, and spatial-temporal analysis can help model the COVID-19 spread at various scales. For example, the COVID-19 network map can be generated based upon the contact tracing of a patient. Such graphs or networks of contacts can help identify super-spreaders or events for super-spreading. Similarly, Bayesian inference methods can facilitate the analysis of disease incidence via time and space.
3) *IoT-based analytics*: Most of us carry or wear the IoT devices in the form of a smartphone, smartwatches, tablets, fit-tracker, and use other electronic devices at our home and

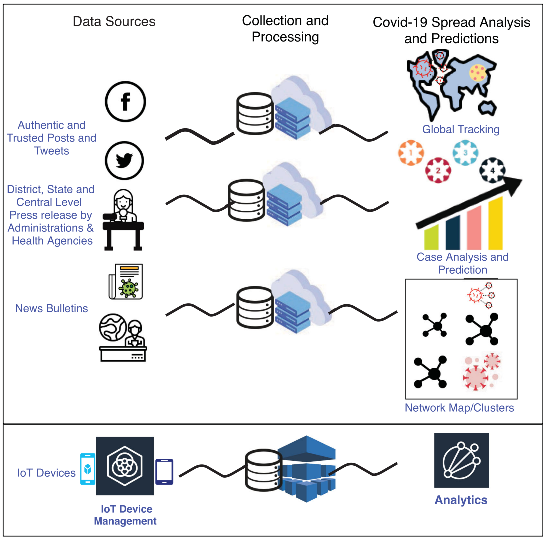

Figure 4. Technology-driven COVID-19 spread analysis.

offices. These IoT devices generate massive data ranging from personal (health), social, behavioral, mobility, etc. Advanced ML algorithms and models can help analyze and predict COVID-19 spread scenarios when applied to those big data collected from IoT devices. However, security and privacy remain the biggest concerns to be addressed.

Thus, advanced analysis and prediction through these technologies can boost awareness, mitigate large outbreaks, and help agencies take proactive, faster, and more precise action to contain and minimize the spreading. The generic view of the technology-driven COVID-19 spread analysis is shown in Figure 4.

SANITIZATION/DISINFECTION

As we all know, COVID-19 spreads by infected secretions (saliva, respiratory droplets) produced as a result of sneezing, coughing, talking, or singing by an infected person.[15] Three possible modes of SARS-CoV-2 transmission include: direct person-to-person transmission (droplet transmission in close contact with infected person),[1] airborne transmission (dissemination of aerosols/droplet nuclei, which remain infectious),[2] and indirect transmission (through contaminated objects and surfaces).[3]

As we come into contact with various objects and visit places for daily needs, medical assistance, and other work, it becomes essential that these objects and places are sanitized to prevent the spread of COVID-19 through indirect transmission. The problems faced with the existing sanitization mechanisms are as follows. (1) Risk of Exposure to cleaning personnel due to highly contagious nature of virus (live up to several days on surfaces and objects in certain conditions). (2) The manual sanitization process is slow, costly, and not much effective (incomplete sanitization). (3) Requires skilled personnel and workforce mobilization. Some of the technology-driven sanitization mechanisms have tried to addressed these issue, which are summarized as follows.

1) *UV robots*: The autonomous or remote-controlled mobile robots mounted with ultraviolet type C (UVC) lamps are being used to disinfect surface and corners, crevices, and the air. Sunburst UV Bot is one such example. These mobile UV robots with adaptive navigation can carry out disinfection autonomously in a cooperative way. The UV robot-based sanitization can be done anytime to any places such as malls, airports/stations, hospitals, offices, homes, and other high-touch surfaces. If radiation is a concern, it can be scheduled accordingly or programmed to turn OFF the lights when there is a human around.
2) *Drones*: The autonomous or remote-controlled drones can help in the sanitization of large and open areas such as roads and religious places. In a remote controlled mode, one person operates it using mobile apps for deployment to selected areas and spraying disinfectant there. More advanced features can be added to make it autonomous so that it can adjust itself to proper height and place, avoid obstacles, return to base station for automated refilling and recharge, and cooperate and communicate with peers for effective sanitization.
3) *IoT*: IoT can help in monitoring our environment and generate alarms for sanitization. For example, managing waste in hospitals, i.e., raising the alarm when a garbage bin is full of PPEs and other disposable protective gear in hospitals. When a patient discharged from the ward, IoT can activate sanitization by sending a message to an automated UV robot. Similarly, when a mall is closed, the

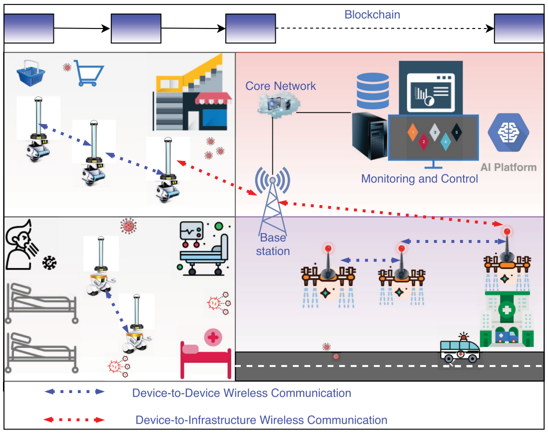

Figure 5. Technology-driven sanitization/ disinfection.

UVC robot can be activated by the IoT to start the sanitization.

4) *AI/ML*: AI/ML's power can help in intelligent detection and navigation of high-risk, contaminated surfaces, objects, and high-touch areas. It can help in making sanitization drones and robots intelligent and autonomous. It can be combined with IoT to monitor the environment and schedule the sanitization process in an automated manner. The sanitizer dispenser powered by IoT, AI, and voice recognition can be used for contactless sanitization of hands. Alexa is one such virtual assistant deployed by the Amazon.
5) *Blockchain*: Most people are afraid of coming out of their homes in this pandemic. We can restore the confidence only when we have technology that ensures that proper sanitization has been done and are available there in place. The places which could not be sanitized and are at risk should also be listed so that people avoid visiting the area. The blockchain has a great role to play here. The entire sanitization process can be recorded in a secure, geo-stamped, immutable, and transparent manner and made available to citizens through the smartphone application. This will make the people aware of safe and unsafe places and ultimately help control the spread.

These technology-based disinfection solutions will be more reliable, safe, fast, cost-effective, efficient for disinfection (reducing contamination at a better scale) and will protect our frontline cleaning personnel. The generic view of the technology-driven COVID-19 sanitization process is shown in Figure 5.

LOCKDOWN, QUARANTINE, AND SELF-ISOLATION

Lockdown

Lockdown, quarantine, and self-isolation are government agencies' measures (enforcements/ advisories) to cut down the COVID-19 spread. Lockdown imposes restrictions on movement, travel, and work in a town, city, state, or country. Quarantine separates and restricts people who are suspected of COVID-19 exposure. For example, those who travel from one place to another are sent to institutional or mandatory two-week home quarantine to see if they too have contracted the virus. People who show symptoms or diagnosed positive of COVID-19 are advised self-isolation. It is an extreme degree of separation, and only medical personnel wearing PPEs are allowed to meet.

These measures and protocols have proven to be useful in controlling the spread. Nonetheless, there are many challenges associated with proper implementations. Some of the key challenges are as follows. (1) Restricted Surveillance: Impossible to physically monitor entire lockdown zones. (2) Challenging to physically monitor whether people in quarantine and isolation are following the instructions and defined guidelines. (3) Ensuring safety and security of healthcare professionals and police officers who visits to monitor all the patients in the quarantine zone are challenging. (4) Health status and symptom tracking (at least twice a day) of people in quarantine and isolation by phone calls or healthcare team visits are not a practical approach. (5) The supply of essentials, food, and medicines to those who are in quarantine and self-isolation is challenging and risky.

Technology-driven solutions (discussed below) can address these challenges and make them more effective (improved surveillance, instant violation reporting, boost safety and security). They can be useful in flattening the curve when adequately implemented.

1) *IoT and AI*: IoT and AI can help to monitor people in lockdown regions and quarantine centers. The information collected via IoT devices

such as CCTV cameras, smartphones (with GPS and set of sensors), wearable devices when uploaded to the cloud, and given to AI models, can reveal whether people are following the protocols or not. For example, it can detect people venturing outside the designated quarantine zone. If found violating guidelines, an alert will be sent to the concerned authorities. Similarly, a wearable designed specifically for patients in isolation can continuously record various health parameters (heart rate, temperature, respiratory rate, oxygen level, body movement, and much more). All these recorded parameters are then sent to the cloud via Internet gateways, where it is analyzed using AI/ML models. If AI models find or predict that patients in isolation or ward may enter into a critical condition, staff or center is immediately informed via an alarm. The list of patients who may be shifted to ICU or need emergency medical assistance can be created and circulated to healthcare stations in an automated way. The IoT and AI-powered voice assistance can also be enhanced for recording speech and coughing to determine the infection. Thus, IoT- and AI-driven solutions will monitor the lakhs of people at an unprecedented rate and assist the authorities in properly implementing protocols and assisting patients in isolation.

2) *Drones and robots*: The drones are used as an "eye in the sky" for surveillance to effectively enforce the lockdown. It can help monitor the quarantined people and check whether they are complying with the protocol or not. The entire drone operations can be coordinated from a central control room. The drone operation can also be set up in an automated way. The powerful cameras (including night visions) mounted on drones captured high-resolution images/videos, which are uploaded to the cloud using highspeed connectivity (4G/5G). These data on the cloud are given to the AI/ML-powered facial recognition and object detection models to identify violations and violators in real-time and send alarms on mobile applications. In addition to surveillance, drones can also be used as megaphones to spread awareness and help deliver essential goods and medical supplies to lockdown and quarantine areas.

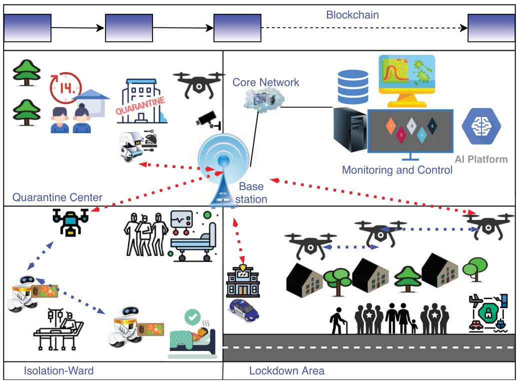

Figure 6. Technologies for lockdown, quarantine, and isolation.

Robots may be used to deliver medicines and food to infected patients in isolation wards. Another set of robots can be deployed for the regular sanitization of quarantine centers and isolation wards. These robots can coordinate with drones for better surveillance and supplies.

3) *Blockchain*: Blockchain can also be helpful (as an integrated solution with IoT and AI) to record some of the important transactions of the aforementioned tasks of surveillance, supply, and assistance in those areas. For example, it can help record transactions of protocol violations and health parameters in critical conditions.

The generic view of technology-driven solution for these purposes is shown in Figure 6.

CASE STUDY: ICT FOR COVID-19 TRANSMISSION NETWORK ANALYSIS

In this section, with the help of an experimental study, we demonstrate how ICT can help in understanding the COVID-19 transmissions, disease outbreaks, and pathogen transmissions in a population. If done at the early stage of virus transmissions, such analysis can help prevent local and community transmission. We investigate the early stage of COVID-19 transmission in Kerala, State of India (case study), using the connection structure. For this purpose, we used open-source data made publicly available by covid19india.org till 12:40 A.M. IST of 11th April 2020. Data were collected using the provided API and were processed to derive the relational information. Transmission network analysis helps identify potential hotspots, super-spreader events (SSEs), or individuals of the disease and have been used in the past for viral infections like MERS.

We use the notation of C1, C2, so on to refer to a different group of nodes. We analyze the derived COVID-19 transmission networks in Kerala based upon two centrality measures.

1) *Degree centrality*: In our context, the value for the degree of a node specifies the number of individuals to which one individual of the network is directly associated. More an individual having direct relationships with other individuals, more are its chances of spreading the disease if he/she is already infected—also, the vice versa—more the connections, more the chances of acquiring the infection.
2) *Betweenness centrality*: In our context, this is the number of infections that would not have happened if an infected individual was not there in the pathway to the newly infected ones in the network.

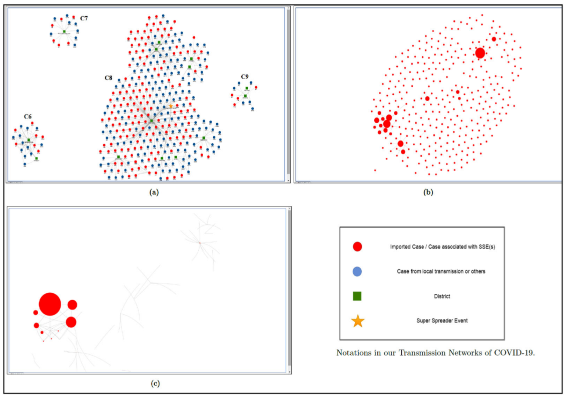

Figure 7. ICT for COVID-19 transmission network analysis in Kerala, State of India.

Kerala was the state where the first case in the country was identified in the Thrissur district. A total of 11 out of 14 districts of the states have witnessed COVID-19 cases till 11th April 2020. Out of 379 detected cases, 11 cases had a direct association with SSE (Nizamuddin Markaz congregation). A series of local transmission from the Pathanamthitta district, which also expanded further to Kottayam district, is observed in C6 of Figure 7(a). An imported case from Italy did infect its relatives and friends, and they, in turn, infected their friends. Figure 7(b) shows the degree centrality network, whereas Figure 7(c) shows the betweenness centrality in the state. There were a total of 364 nodes with 57 connections in the centrality networks. A total of 15.3% of the nodes in the system were having connections to some other nodes in the network. A total of 84.7% of the nodes remained isolated. Nodes in the C6 can be seen to have dominated in terms of betweenness centrality.

With the network centrality measures, namely the degree centrality and the betweenness centrality, we analyzed the connections among the patients of COVID-19 in the Kerala state. We found Nizamuddin Markaz congregation to be an SSE, which significantly increased the state's number of cases. Also, we identified super spreader individuals throughout the state using the centrality measures. Such as the case of Pathanamthitta (Kerala) people returning from Italy. Family and friends component infections display higher interconnectivity than other scenarios of disease transmission as seen in C6 of Figure 7(a). With the betweenness centrality, we find while a patient/individual is directly associated with others, it is not always the pathway to further infections in the network.

A majority of India's households, especially the rural ones, live in a joint family setting in much-limited space. This shared space environment was also responsible for the infection spread in Kerala's Pathanamthitta to Kottayam districts. Thus, much emphasis is required on monitoring and accessing the progress of home-quarantined individuals. Proper tracking of such incoming cases is much needed to prevent new epicenters of the outbreak. A limitation in this study lies in the data accuracy and completeness of the information. The crowd-sourced data comes from sources such as Twitter handles of health ministry (both central and states). Thus, proper contact tracing and accurate and complete information availability are very crucial at the early stage.

CONCLUSION AND RESEARCH SCOPE

Various solutions have been developed using powerful technologies (IoT, AI, robots, drones, blockchain), and many are still under development to combat the spread of the COVID-19. These technology-driven solutions can help to a great extent by minimizing human contact and assist people and authorities on a large scale. These solutions are saving lives of our thousands of frontline corona warriors. The initial results and positive impacts will further accelerate the technology adoption in curbing the pandemic. There are plenty of research opportunities in making all these technology-driven processes effective, fast, reliable, scalable, consistent, transparent, precise, and efficient. The integration of IoT, cloud computing, and robotics into the COVID-19 prevention cycle can lead hackers and adversaries to carry out attacks and exploit user privacy. The accuracy and reliability of these technological catalysts will also play an important role in their wide adoption. Thus, ensuring security, privacy, and trust remains the most prominent research area of this technology integration in dealing with such pandemics.

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