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Explainable AI and Mass Surveillance System-Based Healthcare Framework to Combat COVID-19 Like Pandemics

M. Shamim Hossain, Ghulam Muhammad, and Nadra Guizani

Abstract

Tactile edge technology that focuses on 5G or beyond 5G reveals an exciting approach to control infectious diseases such as COVID-19 internationally. The control of epidemics such as COVID-19 can be managed effectively by exploiting edge computation through the 5G wireless connectivity network. The implementation of a hierarchical edge computing system provides many advantages, such as low latency, scalability, and the protection of application and training model data, enabling COVID-19 to be evaluated by a dependable local edge server. In addition, many deep learning (DL) algorithms suffer from two crucial disadvantages: first, training requires a large COVID-19 dataset consisting of various aspects, which will pose challenges for local councils; second, to acknowledge the outcome, the findings of deep learning require ethical acceptance and clarification by the health care sector, as well as other contributors. In this article, we propose a B5G framework that utilizes the 5G network's low-latency, high-bandwidth functionality to detect COVID-19 using chest X-ray or CT scan images, and to develop a mass surveillance system to monitor social distancing, mask wearing, and body temperature. Three DL models, ResNet50, Deep tree, and Inception v3, are investigated in the proposed framework. Furthermore, blockchain technology is also used to ensure the security of healthcare data.

Introduction

Recent development in wireless technology and machine learning has enabled many service providers to develop lucrative frameworks to satisfy customers and end users. The 5G wireless network consists of three main pillars that aim to provide low latency, faster bitrate, and a large number of Internet of Things (IoT) handling. The rapid outbreak of the COVID-19 global pandemic has revealed the significant requirements and nature of these 5G foundations. However, current resources and available development do not guarantee that all three pillars are achieved at the same time. Therefore, beyond 5G (B5G) or 6G wireless networks have recently emerged to deal with this issue. B5G offers critical solutions to the primary technologies exploited by pandemic conditions, such as wireless awareness, sensing, mapping, connectivity, and positioning. In addition, the three foundations of 5G can be optimized for COVID-19 through different heterogeneous edge devices with an insightful and scalable distribution of dynamically-specified network services in response to network dynamics [1].

For example, a protease sequence dataset will require consistent communication, intense bandwidth, and a low-latency network to conduct efficient training of a deep learning model. In addition, B5G has the capabilities to exploit deep learning models to enable complex network slicing, which can be tailored on the basis of the core COVID-19 deep learning algorithm's GPU requirements, edge or cloud resource needs, spectrum usage, and energy consumption for applications such as mobile broadband, device-to-device connectivity, and large dataset exchange.

Recent progress in the field of fog and mobile edge computing has made B5G even more attractive [2]. The real strength of ultra-low latency communication will exploit the first layer of data processing at the edge where the data is produced. In the case of COVID-19, this specific dimension is important in terms of legislation and data protection. In addition, edge-based processing consumes less power, time and low latency, and cost for data transmission. The need for data analysis using edge technology emerges in situations in which a stake holder must make an immediate decision based on the data being processed.

Millions of people around the world in quarantine depend on their phones to establish communication with the outside world. Furthermore, throughout the world, many of whom have already begun to drive in cities are using their smartphones to navigate an ultra-vigilant civil service network. The Chinese media claims that citizens in several Chinese cities are prohibited from public transit unless they use their phones so that the government can monitor their movement should they later become sick. The Chinese railway authorities may even identify and record the names of citizens who have taken transit in close proximity to a commuter who has later fallen ill with COVID-19. In fact, citizens who wish to leave quarantine conditions can send a text message to their provider and receive a map of the cities and regions where they have travelled over the previous two weeks. For certain situations, this may act as proof that the risk of individual disclosure is fairly small.

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The role of wireless technology is not restricted to a specific area. For instance, data obtained from mobile network providers has allowed scientists to forecast the next global epidemic from the recent epidemic. The promise of B5G or 6G is significant, delivering faster download speeds, with future possibilities of speeds up to one terabit per second. Collaborations between intelligent agents that solve issues and negotiate solutions regarding complex problems will thus undergo rapid change. For example, future self-driving cars will need to be mindful of their position, surroundings, and the ways in which they are evolving, along with other road users such as bikes, pedestrians, and other self-driving vehicles. They will also be required to navigate across junctions and refine their paths in such a way as to reduce travel time. Vehicles may be required to instantly create on-the-fly networks; for example, upon reaching a particular junction, they may then leave it almost immediately. Simultaneously, they will also be a part of wider networks that estimate routes and travel times, among other aspects. Interactions will also be required in significant quantities to solve major dispersed problems in which significant convergence, high data volumes, and ultra-low latency within 5G networks are critical.

In the midst of an epidemic, 5G carriers, hardware suppliers, and industrial device software vendors are working together to contain and deter the dissemination of COVID-19. To date, a number of 5G applications have been deployed to include COVID-19 in terms of laboratory tests, predictions, and recognitions. With regard to B5G telemedicine, a service provider can develop a B5G COVID-19 teleconsultation system with the help of researchers, scientists, and medical institutions to manage acute and critical COVID-19 cases. The service provider can also introduce the 5G-based portal for free COVID-19 diagnosis and medical care. To address a lack of radiologists, it can also support hospitals using a CT and X-ray synchronization system focused on 5G cloud partnership for the accurate detection of CT and other images in the screening of alleged COVID-19 incidents. In addition, the provider company can facilitate visual coordination from both inside and outside isolation centers for confirmed cases to allow specialists to perform telemedicine on the basis of information sent over 5G networks, such as ECG data monitoring and ultrasonic images, thereby enhancing the medical treatment potential for urgent and serious cases. A 5G cloud-based smart robot can be developed to conduct remote health care, body temperature monitoring, sanitization, washing, and medication distribution. This potentially reduces the chance of cross-infection and enhances ward segregation management. As such, 5G IT-based infrared temperature monitoring has already been used in traffic centers to track passenger conditions in a variety of cities.

Regarding B5G digital media, an emergency strategy for B5G cloud live streaming can be developed and, via the 5G+ fiber optic dual gigabit network, several hospitals can be continually live-streamed on the CCTV site, which users alluded to as the communication with the most reach. It can also be used to disseminate information on COVID-19 prevention and management via its 5G full-screen video ringback tone facilities. In support of B5G virtual education during the pandemic, this knowledge can provide the maximum benefit of 5G networks and information technologies to disseminate free computing tools and educational facilities, such as online streaming of distance education, and synchronous classrooms. With the aid of these remote classrooms and instructional sites, city-level and county-level primary and secondary schools will mobilize their teachers and students to teach and study from home with their original classes and grades intact, eliminating the assembly of students during the epidemic and minimizing the chance of infectious transmission.

> B5G combined with deep COVID-19 vertical training would facilitate low-latency, high-quality video streaming for medical staff to effectively diagnose patients remotely, vastly enhance regional access to medical information, allow physicians located outside locked-down epicenters to recognize CT and X-ray specimens, and help alleviate the diagnostic pressure on local physicians.

One of several difficulties confronting the real-time epidemic monitoring and control system is the need for vast amounts of pathological, radiographic, genetic, and other types of epidemic-related information to be absorbed, stored, processed, and classified based on large amounts of COVID-19-related data. Human physicians require real-time support at the front-line COVID-19 treatment point-of-care facilities, along with more efficient diagnosis. Deep Neural Networks (DNN) have been widely used to handle massive volumes of epidemic data and predict live epidemic crises.

MRI, CT Scan, and PET scan samples using DNN lung disease inference have obtained an appropriate accuracy, indicating a possible aspect of COVID-19 treatment through radiological inference. For instance, researchers have used image recognition-dependent DNN models that demonstrated optimum results regarding COVID-19 medical image processing by training a model using COVID-19 datasets, which are immediately available from credible sources dependent on the WHO. These models therefore have the potential to function in clinical trials involving live cases of COVID-19. Besides radiological media such as CT scanning and X-ray samples, current work has shown that DNN has been effectively validated to recognize COVID-19 from other medical symptoms. Examples include audio media such as cough signals, uses of Optical Coherence Tomography (OCT) for detecting conjunctivitis or pink eye, and body temperature analysis utilizing a thermal camera or a mobile fingerprint sensor to classify individuals.

Since COVID-19 threatens the epithelial cells of our respiratory tract, physicians have used CT scans to assess patients' lung health. Given that practically all hospitals are equipped with CT scans or X-ray imaging devices, these technologies could be used for screening COVID-19. One of the constraints of CT scanning and X-ray image processing is that they require radiology experts and are time-consuming, which is a problem for patients who require an immediate COVID-19 diagnosis. For this reason, it is necessary to develop an automated assessment model to save precious time for health care experts and to subsequently serve more people [3].

During a pandemic such as COVID-19, we need a centralized edge cloud-based deep learning platform where research, evaluation, monitoring, and inference can occur. Having it at the edge of the hospital network enables regional initiatives to achieve large real-time data analysis, and to infer reliable outcomes through both regional and global avenues. Infection epicenters or "hotspots," locations that experience the largest number of COVID-19 victims, will generate a vast number of live different-dimensional datasets that can be exchanged across 5G networks to be used by AI and the Deep Neural Network group across the world to train the corresponding DNN [4].

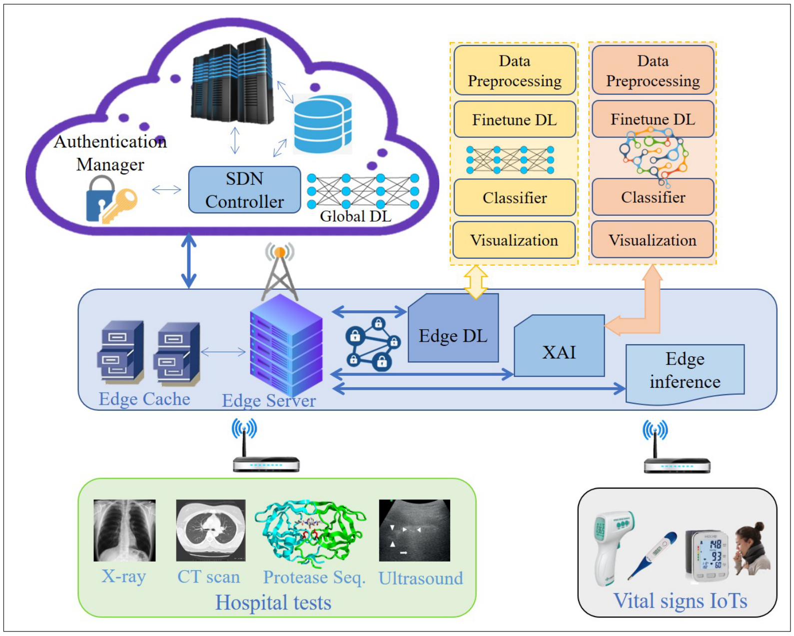

FIGURE 1. Proposed health care framework utilizing three layers. The bottom layer consists of hospitals, homes, and stakeholders; the middle layer contains edge computing; the top layer consists of the core cloud.

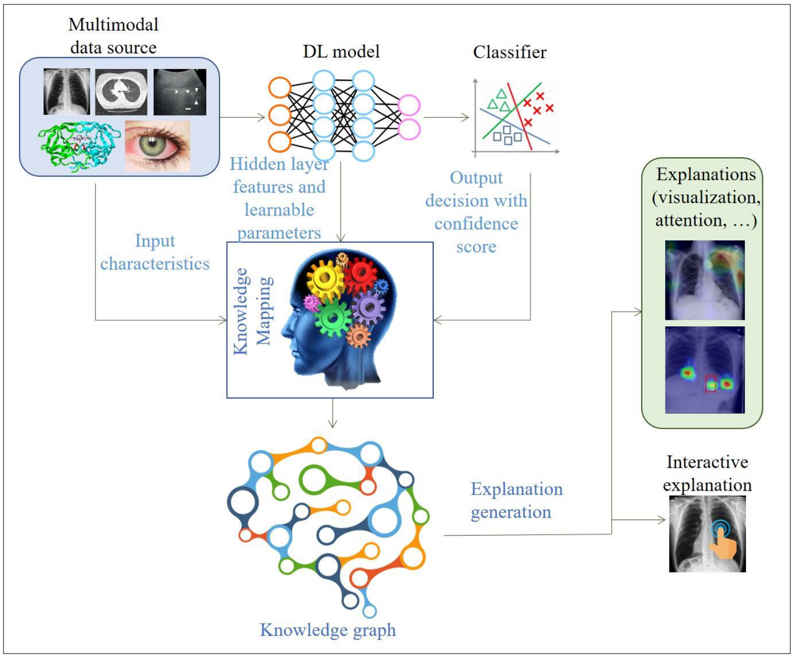

FIGURE 2. Illustration of XAI process. A knowledge graph is produced using inputs, learnable parameters of different DL layers, and output probabilities.

B5G combined with deep COVID-19 vertical training would facilitate low-latency, high-quality video streaming for medical staff to effectively diagnose patients remotely, vastly enhance regional access to medical information, allow physicians located outside locked-down epicenters to recognize CT and X-ray specimens, and help alleviate the diagnostic pressure on local physicians. It would also minimize the number of individuals coming into contact with the illness, particularly in respect to distant medical staff, as well as high-risk individuals with chronic conditions who may have likely received diagnostic and medical access at the facility.

Proposed Framework

Figure 1 illustrates the proposed smart health care framework to combat COVID-19-like pandemics. There are three main layers in the framework. The bottom layer denoted as the user layer, consists of stakeholders and beneficiaries such as hospitals, user homes, and decision-making and monitoring entities. The middle layer, the edge layer, consists of the edge server, edge caches, and edge nodes. Meanwhile, the top layer contains the core cloud, which hosts the servers and global storage. At the bottom layer, specific data types (CT scan, X-ray, ultrasound, and so on) are gathered during hospital tests. For vital signs such as body temperature, blood pressure, heart rate, and cough quality, this data may be collected through an app at the user's house. A patient who suspects infection may use their mobile phone app to record and upload vital signs to a hospital data center. An AI module would then categorize whether these signals are normal or require more examination.

A deep learning (DL) model is trained in the core cloud. The cloud contains servers with high computation power consisting of multiple GPUs. It also has global storage, in which different types of physiological signals and hospital test signals are stored. These signals may include chest X-ray images, CT-scan images, protease sequences, ocular surface images, cough sounds, body temperature, blood pressure, and so on. These signals are gathered from all registered hospitals and stakeholders. We adopt three types of DL models: ResNet50, deep tree, and Inception v3. These models employ images as input. There are many DL models; however, these three performed the best in the literature either in terms of information density, or accuracy, or having a trade-off between them. For temporal domain signals, we convert them into spectrums for subsequent processing. The DL model has a parallel stream, in which each stream of data represents one type of signal; for example, there exists one stream for CT scan images, one for X-ray images, and so on. Each stream runs independently and is fused at the final level of decision. In this way, should any modality be absent, there will be no issues around decision-making.

The middle layer uses the trained DL model, which is downloaded to the network edge from the cloud during off-peak times. The edge server is closely located to the designated hospital and neighborhood. When a test is available, the sample is sent to the edge via WiFi. The edge server

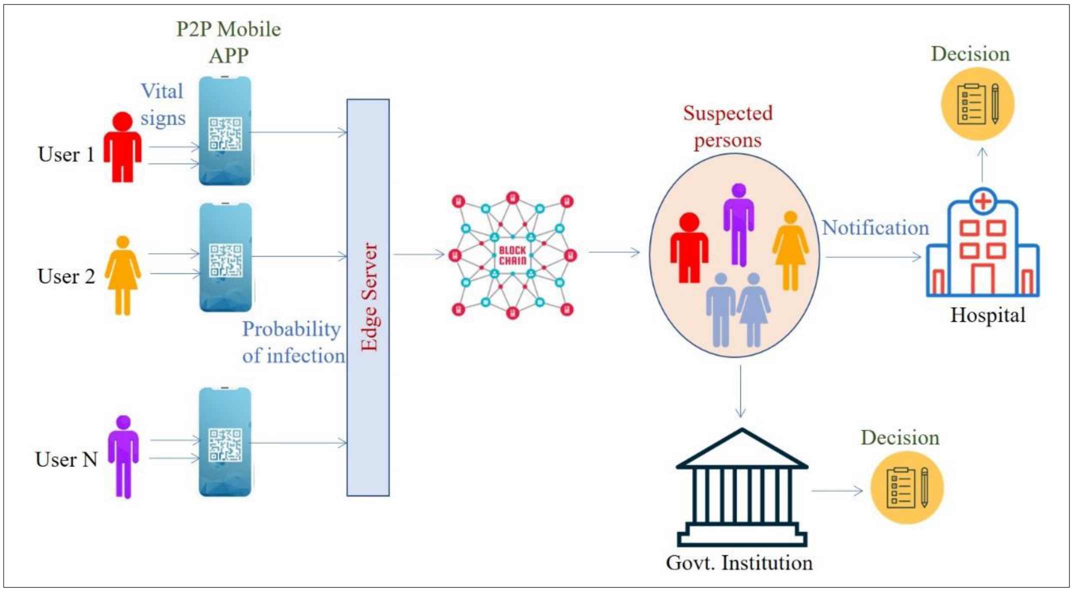

FIGURE 3. Illustration of the self-detection of probable cases using the P2P mobile app.

first secures the data using blockchain technology, and then sends the data to the DL model. The server also uses an explainable AI (XAI) to allow doctors to understand the outputs of each layer of the DL model [5]. The XAI can be achieved through the visualization of layers as well as confidence scores. Edge caches are used to store the learnable parameters of the DL model for instant access.

In the edge XAI module, the outputs are produced through a process shown in Fig. 2. Knowledge mapping takes inputs from the multimodal data source, such as images from CT scans, X-rays, and ultrasounds, as well as protease sequence data, ocular surfaces, output probabilities (confidence scores), and learnable parameters from different layers of the DL model. Knowledge mapping uses Local Interpretable Model-Agnostic (LIMA) explanations [6]. This strategy involves interrupting inputs to observe the impact on the outputs of the model. This allows us to build a focused image of the model's inputs and what it uses to make predictions. LIMA functions as follows: starting from an input image, it uses a black-box DL model to create a distribution of the likelihood over the classes. Next, it interrupts the feedback in some way; for the image, this might involve covering the pixels by making them white. LIMA then processes this into the black-box DL model to verify whether the odds for the class it had initially expected have improved. This process employs an interpretable (usually linear) construct such as a knowledge graph on the dataset of disruptions and probabilities to derive the core features that describe the adjustments. The explanations are then generated in the form of visualization and attention. We use the gradient-weighted class activation mapping (gradCAM) algorithm to visualize.

Self-Detection of Likely Cases of Infection Within the Human Group

The peer-to-peer (P2P) networking architecture of P2P mobile apps, their capacity for shared storage, time-stamping, and the real-time computing advantages of blockchain, will make it possible to identify the origin of infections among a crowded group of people [7]. This can be accomplished by sharing the likelihood of infection between individuals utilizing the P2P mobile application of each individual. Furthermore, as you join a crowded cluster of people or a particular individual nearby, the P2P mobile app will instantly generate an alert notification from all nearby individuals. The received alert message contains the user identity of all individuals with a probability rate of infection. In this way, the individual could then scan all received alert messages and use the P2P mobile software to coordinate them at the maximum risk rate of infection, which ensures that the individual may take the appropriate measures against suspected contaminated cases that pose a high risk of infection [8]. Figure 3 illustrates the self-detection mechanism using the P2P mobile app.

Mass Surveillance System

Due to emerging threats to the safety of citizens and nations, many e-governments (e.g., China, USA, Australia, Germany, Russia, and so on) have begun tracking the movement and behavior of all residents by installing a number of mass surveillance system points in all the towns, villages, streets, and public spaces to track and monitor suspects and detect suspicious patterns.

Using a detection and tracking function, the mass surveillance system can identify, locate, and specify the identity of individuals for safety or health reasons. Therefore, this function can be called upon to monitor the previous movement behavior of confirmed COVID-19 cases in order to detect the set of individuals who may have been in close contact with the infected case, as well as locations recently accessed by the COVID-19 patients. Governments and hospitals are able to identify suspected cases and high-risk infected areas that have been recently visited by reported cases of COVID-19 using blockchain technology. The block of the blockchain has two parts: block header and block

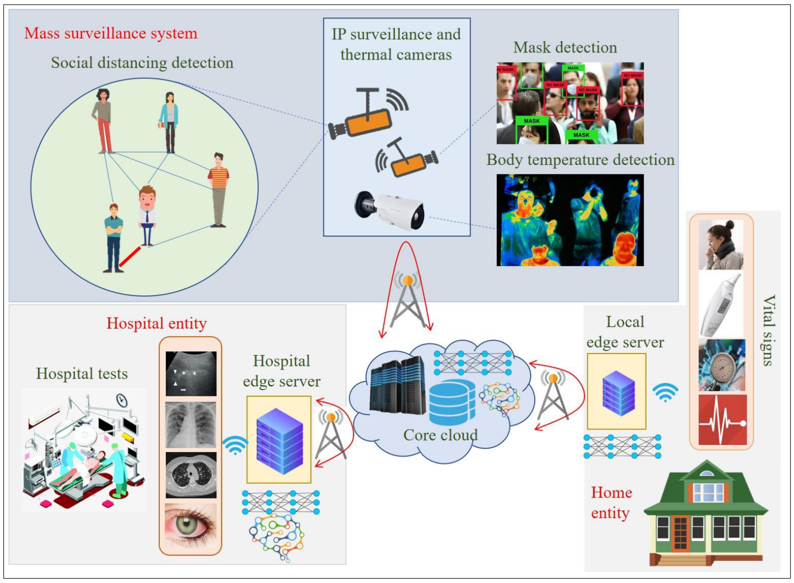

FIGURE 4. Illustration of how the mass surveillance system integrates into the proposed health care framework.

body. The block header consists of five components: block version, previous block hash code, Markle root, block hash code, and time-stamp. The block body has two components: infection pattern generator and infection pattern. The infection pattern is generated by using a finite automata model.

Using a blockchain feedback feature, a mass surveillance system calls for this method to send the identified collection of likely infected individuals, as well as the collection of infected locations to the blockchain. This will map the set of infected individuals, and their locations related to reported cases of COVID-19, and encodes them in the form of infection trends and companion infections. Blockchain and the mass surveillance system work together as follows: First, the blockchain submits a request to the mass surveillance network for a particular COVID-19-confirmed scenario. Next, the mass surveillance device would call the blockchain input features to optimize the monitoring request and transfer it to the identification and tracking framework for implementation. When the identification and tracking mechanism has been effective in detecting and identifying all probable infected individuals and their locations, the results are returned to the blockchain feedback feature. This triggers the mass-surveillance device to submit the necessary tracking results.

Figure 4 presents how the mass surveillance system integrates into the proposed health care framework. The framework consists of a hospital entity where tests for COVID-19-like pandemics are carried out, a home entity where vital signs can be measured, and a mass surveillance system that monitors individuals regarding social distancing, mask wearing, and body temperature. The system can perform different functionalities such as social distancing detection, mask (wearing) detection, and body temperature monitoring. IP surveillance and thermal cameras can be used for this purpose. The captured signals are sent to the cloud where the DL model is run and decisions are then made. For mask detecting, the Viola-Jones face detection algorithm was applied first. Then, the features are extracted from the face area using the DL model.

Scenarios in Which 5G Can Help Combat COVID-19-Like Pandemics

5G networks have greater capacity and volume, reduced latency, and utilize narrower connectivity relative to 4G networks. 4G will accommodate these three possibilities with increased universal coverage, ultra-stable low latency and wide connectivity [9]. The strategic collaboration of 5G into economic and social sectors will give rise to rapidly growing information products and services and help to reduce and regulate COVID-19 from three perspectives.

A Majority of 5G Applications Can Improve Health Care, News Media, and Distance Education

In the health care sector, apart from HD teleconsulting, 5G increases the capacity of grassroots and community-based medical organizations to cope with the disease, while decreasing the possibility of person-to-person infection distributed through local regions. It makes possible the usage of cloud-based medical and nursing robotics, as well as robots for disinfection and cleaning, product distribution, and tempering [10].

In terms of media coverage, 5G will flexibly enable 4K/8K HD live broadcasting on a 24-hour basis in crucial disease management zones and satisfy the video sharing requirements of large HD cameras and terminal recorders. Moreover, as wireless connectivity is not confined to bandwidth, 5G will provide more robust ultra-high-resolution video (UHDV) playback. This allows the processing of video footage online using cloud-based video production software, and the distribution of material in order to update citizens around the country on disease trends [11].

In the education sector, the integration of 5G with technology such as UHDV, VR/AR, and holography can push boundaries in education and offer interactive classroom experiences. Students may have a clear sense of presence via HD displays, HoloLens, and VR/AR terminals, among other things to replicate the in-person experience of their instructors and the impact of real-world educational aids and resources.

5G Intelligent Industries and Cruise Control Devices Can Increase the Productivity of Commodity Output and Transport

During times of disease prevention and control, manufacturers are no longer able to function as expected, resulting in a scarcity of medical supplies, which magnifies the value of intelligent and automated manufacturing. Due to its ultra-low latency, 5G can fulfill the connectivity criteria of machinery in factories and enable intelligent output in factories through remote control and other devices, thereby prohibiting operators from accessing dangerous areas. Unmanned 5G AGVs (Automatic Guided Vehicles) can be utilized in a wide range of situations, such as quality inspection, device detection, and automatic identification. As far as

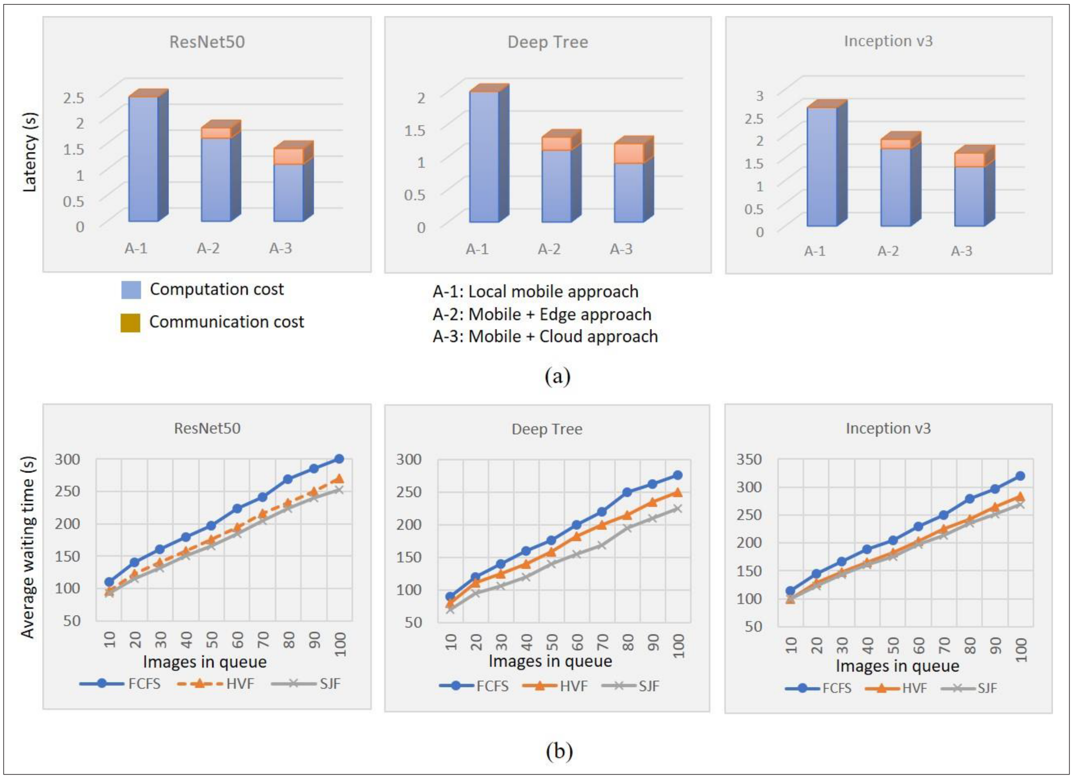

FIGURE 5. a) Inference latency (s) in each of the approaches using three different DL models are shown; b) average waiting time (s) for three different scheduling algorithms using DL models are shown.

transporting essential materials is concerned, 5G will help to acquire real-time details regarding local traffic and the driving conditions of automobiles a few hundred kilometers away. 5G will also be able to move hazardous goods and articles to and from contaminated areas by means of monitoring start-up, acceleration and deceleration, braking and other driving operations, and to fulfill the need for essential supplies [12].

Diversified 5G Networks Can Provide Modern Forms of Disease Monitoring and Security in Public Areas

In crowded areas such as hotels, pubs, recreational facilities, shopping centers, grocery stores, and public transit stations, 5G infrared thermal imaging temperature sensors may be used to monitor multiple users at a time. The major functions of 5G-networked UAVs, such as real-time UHD image transmission and distant low-latency control, will augment the forms in which UAVs are used in both epidemic and advertising surveillance [13]. 5G UAVs fitted with a thermal imaging network will conduct real-time aerial surveillance of a heavily populated outdoor space. 5G UAV voice broadcasting systems can conduct aerial broadcasts to alert individuals to take precautions when suspected cases are detected. Plant safety UAVs will also spray disinfectants on city highways, cultural parks, leisure centers, and country areas to improve disinfection capacity. Multiple edge servers at different locations can be deployed to make the processing fast and to alleviate the load of transferring a huge volume of data to the cloud [14]. A good optimization algorithm can distribute and communicate between the servers [15].

Experiments

As a working prototype, we conducted multiple tests on chest CT-scan images to determine whether they belong to healthy, non-COVID-19, or COVID-19 patients. In fact, minimal data on COVID-19 is accessible in public archives and could be included in the planned AI-based method. There exist a number of Kaggle and Github repositories for hosting chest X-ray and CT scan images. For the tests, images were divided into training and testing sets. The number of samples per set was as follows: the training set had 2000 healthy samples, 2000 pneumonia samples (non-COVID-19), and 200 COVID-19 samples; the testing set consisted of 200, 200, and 50 samples, respectively. We conducted experiments using the five-fold validation method, in which the samples in the training and testing sets were mutually exclusive for each iteration. The training samples were augmented by rotating between 5 and 35, scaling horizontally and vertically, with a scale between 0.8 and 1.2.

Different open-source libraries such as PyTorch, Tensorflow, Keras, Pandas, Ploty, pysim5G, matplotlib, Docker, pickle, Openpose, OpenCV, and Numpy were used for implementation. The local edge processor was built utilizing the NVIDIA GeForce GTX 1080 8 GB GPU, the CUDA 10.2.108 driver, and cuDNN 7.6 software. The edge server was an NVIDIA Jetson T2. Several Python modules were used to verify the 5G edge application protocols at the ultra-edge and base stations.

In the experiments, three approaches were investigated: a local mobile approach, a local mobile with edge approach, and a local mobile with cloud approach. In the local mobile approach, an interface was developed in a Sam-

In a future work, other DL models and protease sequence analysis will be tested in the framework. Other future directions can be to embed a prediction model and a time-series analysis model as part of the framework. In addition, pervasive edge computing can be used for low latency and better security.

sung Galaxy S20 Plus, 128GB smartphone running Android version 10. The inference latency (s) was measured by these three approaches. Figure 5a shows the results using three DL models: ResNet50, deep tree, and Inception v3. From the results, we find that the deep tree model had the lowest latency. There was negligible cost difference between the edge and cloud approaches. This therefore proved the success of the edge-based health care framework.

Three scheduling algorithms were investigated in the framework for different numbers of samples in the queue. The algorithms are first-come first-serve (FCFS), highest value first (HVF), and shortest job first (SJF). The average waiting time per sample in the queue was measured for the three DL models. Figure 5b shows the results, in which SJF scheduling presented the least amount of waiting time. From the results shown in Fig. 5, we understand that the deep model is more suitable than ResNet50 and Inception v3 in the proposed health care framework.

Conclusion and Future Work

A B5G-enabled smart health care framework was proposed to combat COVID-19-like pandemics. The framework has a stakeholder layer, an edge layer, and a cloud layer. A mass surveillance system in terms of social distancing, mask-wearing, and body temperature detection was integrated into the system. The hospital test data and human vital signs were analyzed at the edge utilizing the latest generation of high-power edge computers. The proposed COVID-19 diagnostic method may be extended to any infectious disease. It will therefore help to reduce overcrowding in hospitals, to verify non-COVID-19 patients, and to process sensitive personal data at the edge to protect anonymity.

In a future work, other DL models and protease sequence analysis will be tested in the framework. Other future directions can be to embed a prediction model and a time-series analysis model as part of the framework. In addition, pervasive edge computing can be used for low latency and better security.

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