

Received 3 August 2022, accepted 26 August 2022, date of publication 31 August 2022, date of current version 14 September 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3203061

RESEARCH ARTICLE

6G Driven Fast Computational Networking Framework for Healthcare Applications

PARVATHANENI NAGA SRINIVASU¹, MUHAMMAD FAZAL IJAZ², (Member, IEEE), JANA SHAFI³, MARCIN WOŹNIAK⁴, AND R. SUJATHA⁵

¹Department of Computer Science and Engineering, Prasad V. Potluri Siddhartha Institute of Technology, Vijayawada 520007, India

²Department of Intelligent Mechatronics Engineering, Sejong University, Seoul 05006, South Korea

³Department of Computer Science, College of Arts and Science, Prince Sattam bin Abdulaziz University, Wadi Ad-Dawasir 11991, Saudi Arabia

⁴Faculty of Applied Mathematics, Silesian University of Technology, 44100 Gliwice, Poland

⁵School of Information Technology and Engineering, Vellore Institute of Technology, Vellore 632 014, India

Corresponding authors: Muhammad Fazal Ijaz (fazal@sejong.ac.kr) and Marcin Woźniak (marcin.wozniak@polsl.pl)

This work was supported by the Rector of the Silesian University of Technology, Gliwice, Poland, under Grant 09/010/RGJ22/0068. The work of Jana Shafi was supported by the Deanship of Scientific Research, Prince Sattam bin Abdulaziz University.

ABSTRACT New Sixth-generation (6G) networks rely heavily on the Intelligence Internet of Things (IIoT) to store and process data more efficiently. 6G is desired to offer ultra-low latency, high bandwidth, and improvised quality of service that can effectively handle the communication among the nodes. All the healthcare facilities must be outfitted with cutting-edge technology to assist the individual with intelligent diagnosis, patient-centric treatment, and a range of other healthcare services both in the hospital and remotely. To make the system ready and adaptable to the technology and provide services to divergent applications ranging from robotic surgeries to remote monitoring of the patients through wearable technologies in an Ambient Assistive Living (AAL) environment over the intelligent networking platform. Various networking nodes and terminal devices provide the services for applications in the healthcare domain, which needs a backbone framework to deliberate the time-intensive services. This paper proposes a reference layered communication framework for the nodes and devices in real-time communication. The feature perspective aspects of 6G technology present the futuristic healthcare application for effective treatment and smart integration of services.

INDEX TERMS 6G technology, 5G technology, reference framework, algorithm, healthcare, remote robotic surgery.

I. INTRODUCTION

For the 6G Network, all aspects of real and digital environments are brought together. We anticipate more automation to take place within the next few decades. The sheer number of objects will need to synchronize knowledge disseminated across the communication infrastructure rather than private networks. More importantly, communication among peers and automated processing capabilities for safe and reliable operations in 6G. They were promoting new marketplace innovations that will allow a digital revolution in 2030 and beyond by ensuring that network infrastructure and apps communicate efficiently with one another. One of the

The associate editor coordinating the review of this manuscript and approving it for publication was Xujie Li.

primary advantages of 6g networks is that they can handle more extensive mobile connections for sensing remote data than the fifth-generation (5G) network. That results in less interference between devices, resulting in a better service. The devices would work at broader frequencies, i.e., in the range of 8 to 12Ghz, allowing the sensor and communication devices to communicate seamlessly without overlapping the frequencies. With 97 billion devices expected by 2030, the worldwide mobile-produced data traffic is expected to rise to 5.016 Zeta Bytes (ZB) monthly usage from the current 0.062 ZB [1]. According to a poll, more than 10 million people will live in 43 megacities worldwide by 2030. The vast amounts of data created by mobile devices and smart city ecosystems, including smart healthcare, and intelligent cities, need smart Information, Communication, and Technology

(ICTs) that are flexible and strong. Internet of Everything (IoE), among many others, creates enormous amounts of data, feeding the generated data. Mobile phone networks are expected to significantly influence these verticals' high-bandwidth needs and high Quality-of-service (QoS) [2].

Antennas that are extremely directional with Massive bandwidth will be made accessible to 6G equipped devices through millimeter-wave (mmWave) and terahertz (THz) frequency bands, ensuring the new application services and seamless coverage. In 2019, the Federal Communications Commission commercialized [3] these frequency channels. Owing to ultrahigh-resolution imaging technology and gradient sensors, with identical capabilities to human eyes and ears, ultra-precise location will be accessible with 6G. 6G gadgets may include competent robots and sophisticated algorithms [4]. 6G is intended to be a completely AI-driven network system that deals with massive amounts of data and necessitates different degrees of QoS. Endorsing these duties enables effective analysis, summarizing, refining, and decision-making abilities. AI will be ubiquitous in decentralized 6G infrastructure, where many network components will use federated learning for disseminating collaborative services. AI will operate in decentralized learning agents at various network entities, benefiting people and the whole network as a collective operation. AI algorithms might be incorporated into the radio access networks to disseminate cognitive skills for systematic channel allocation and prioritizing among the physical channels such as Terahertz band, visible light communication, and satellite connection, along with managing the transmission power, and modulation scheme options. Using appropriate data learning techniques, AI at the application layer would handle various smart operations, including smart healthcare and Ambient Assistive environments, with enhanced performance [5].

The 5G technologies have adopted the technologies like enhanced mobile broadband (eMBB) [6], ultra-reliable and low-latency communication (URLCC) [7], and massive machine-type communication (mMTC) [8] to prove better communication among the peers that work over the 5G network. Later they are upgraded to eMBB+, URLCC+, and mMTC+ in the advanced 5G technology [9]. However, 6G will greatly broaden the technical environment, allowing for the support of immersive communication technology that includes enhanced Spatio-temporal services and native AI-driven capabilities for communication. The 6G network not only supports the services provided in the previous generations but also endorses the new services with the inclusion of new technology like high-level digital twinning, Embedded systems everywhere, multi-sensor data fusion to create multi-verse maps, and Autonomous systems. The most critical demand for 6G wireless networks is the ability to handle massive volumes of data at a very data rate per device [10]. Backscatter communications might enable battery-free or zero-energy devices in 6G, allowing huge data collection for analytics and closed-loop control [11].

When transatlantic telesurgery on a patient is performed in 2001 in New York., no packets were lost during the transmission since the connection was in the specialized Asynchronous Transfer Mode (ATM) through fiber optics [12]. Telesurgery, although a successful demonstration, has not been extensively employed. Because of the high cost of connectivity, considerable latency, and no assurance of dependability provided by the public Internet, this is the primary factor. Based on visual input, some study has examined how delay impacts telesurgical performance using the robotic simulator dV-Trainer. It is extremely important for ultra-low latency communication while performing robotic surgical operations. It is projected that 6G technological advancement will radically change healthcare and that healthcare will wholly rely on communication technology. It will demonstrate the paradigm change in healthcare brought about by the advancement of communication technologies [13]. Various cellular technologies are presented in Figure 1.

This paper primarily focuses on the crucial 6G network strategies for the healthcare domain. Among other things, we present a full discussion of applications, potential challenges associated with the healthcare domain, and the layered frameworks of 6G technology for healthcare applications. These are our main takeaways from all of the current studies we read:

- Presenting the technical transformation of 5G/5G+ technologies to 6G.
- Discuss how smart applications and time-sensitive services in the healthcare industry may be taken over by 6G technology.
- Take a closer look at the communication issues and potential challenges associated with Healthcare applications.
- Present the single-system architecture for 6G communication technology to ensure QoS for healthcare applications.
- Presenting the 6G framework for the terminal and networking devices.
- Feature perspectives of intelligent 6G technology in healthcare applications.

The rest of the paper is organized as follows, and Section 2 presents the role of 6G technology in the healthcare domain. Section 3 presents the reference framework for the healthcare applications, including the framework for both terminal and network nodes. Section 4 presents the feature perspective of the healthcare domain over the 6G architecture. Section 5 elaborates on the takeover of 6G technology in addressing the associated potential challenges. Section 6 discusses the conclusion of the study.

II. ROLE OF 6G IN THE HEALTHCARE DOMAIN

The transformation to 6G technology has facilitated a tremendous improvement in the biomedical and healthcare engineering sector. The technology is expected to revolutionize the sector from remote activity surveillance to remote robotic surgery in the most efficient way [24]. Intelligent technology

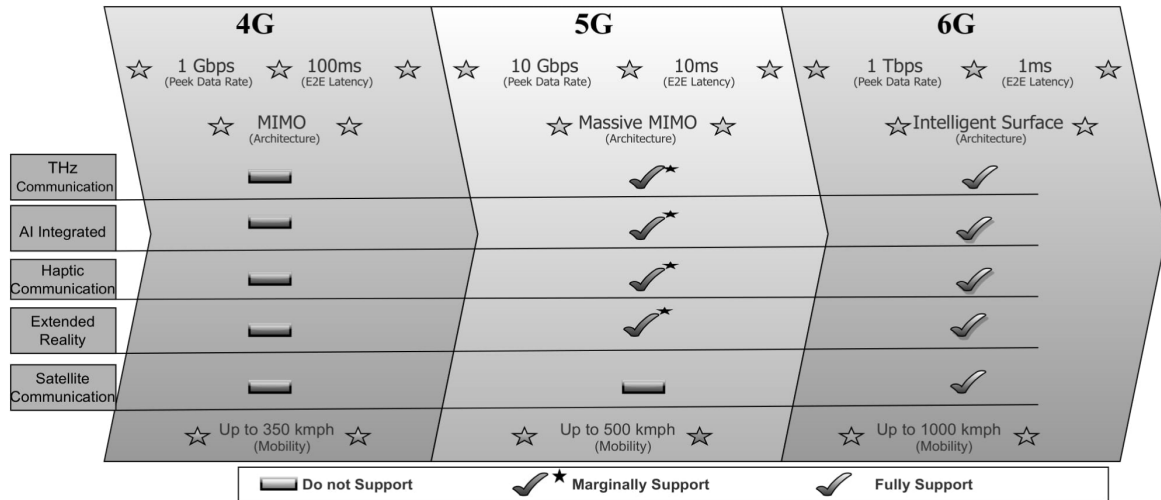


FIGURE 1. Analysis of various cellular technologies.

would assist in making smarter decisions on the fly. In the 6G network, the networking operations, data processing, resource management, and service-based communication are driven by Artificial Intelligence, which makes them tailored to work in divergent environments to provide better services. The technical developments and enormous data needs in healthcare have resulted in the revolutionary foundations of 6G, which will leverage current technology trends and new requirements to expand and build ecosystems for wireless communication in the healthcare domain. 6G robotics may be used to create remote surgery so that distant physicians can manage the procedure using robotic devices with millisecond latency and great dependability [25]. The telemedicine services and the AAL technologies for monitoring elderly people and providing them with timely treatment would be better assisted by the 6G-based intelligent network [13], [26].

Healthcare application is no longer confined to the patients or individuals with illness, which now features to provide services and enhance the living standards of the individuals [27]. A few featured services include Emergency services, Intelligent Wearable Devices (IWD), Hospital-to-Home services, remote pharmacy, surgeries by physicians, insurance services, ambulance services, and so on part of the healthcare services. IWD is among those services that will benefit patients significantly [28]. IWD, for example, sends information on cardiac rate, health issues, blood tests and pressure, body weight, and dietary intake. As a consequence, IWD will make patients' life easier and minimize the frequency of hospital visits or stays at home for longer periods of time. Figure 1 presents the healthcare applications integrated over the 6G technology.

Furthermore, Wireless Body Area Networks (WBANs) improve device performance [29]. WBANs must extend network life and provide emergency data within recognized reliability to enhance performance [30]. In addition, other services include remote robotic surgery with latency

(<1 ms) [31]. Remote robotic surgery requires networks with extremely high reliability in data exchange, the accuracy of the data being delivered, and extremely high transfer rates to share information among the remote health centers. Healthcare networks should not be characterized as traditional wireless networks to ensure QoS necessities. This organization needs portability, enormous compliance support, tremendously low latency (<1 ms), green communication for patient security, and continuous connection availability. The technologies like the Internet of Medical Things [32] and the Internet of Nano Things [33] for body-level communication are made technologically feasible in deliberating their patient-centric services.

6G is the most suitable choice for hosting healthcare networks for these requirements. 6G networks will transform the healthcare industry. 6G is a strong competitor for assisting the healthcare network with dependability, mobility, capacity support, and security. [34], [35].

III. 6G REFERENCE FRAMEWORK FOR HEALTHCARE APPLICATIONS

The current section presents the layered reference framework of the 6G technology that acts as the backbone for integrating multiple network applications with their related services to ensure seamless data communication among the nodes. The 6G technology has offered superior features and enhanced network capabilities that could have better operational flexibilities. The enhanced spectrum, ultra-low latency, ensured QoS, integrated intelligence, inbuilt optimization capabilities, Wider Integration capabilities, Air Interface, and reduced operational cost are few among the mighty features of 6G that would remove the barrier the time and space barrier for the devices to communicate. Co-designing communication and administration will result in reduced costs, more excellent data rates, and an increase in the number of healthcare applications. The 6G network will allow combined

TABLE 1. Various technologies are used in the healthcare domain.

Technology	Application	Features
4G	Built a telemedicine system for wound diagnosis and treatment using 4G optical fiber and high-resolution video [14].	Telemedicine system
4G	Mobile femtocell (Mfemto) is a novel tiny cell network technology idea. Mobile femtocells are distinguished by their ability to roam about, and rapid connection to the operator's core network in their neighborhood for better ambulance services [15].	Smart ambulance services
5G/5G+	Using a smartphone over 5G technology, patients with chronic pulmonary disease were monitored at their home location [16][17].	Ambient Assisted telemedicine services.
5G/5G+	5G robot-assisted remote ultrasonography successfully assesses COVID-19 patients with cardiopulmonary status [18].	Tele-ultrasound services.
5G/5G+	Used in Lap operations for patients in Spain [19][20].	Tele-mentored surgery.
5G/5G+	B5G framework that uses the low-latency, the high-bandwidth capability of the 5G network to identify COVID-19 utilizing chest X-ray or CT scan pictures and construct a massive surveillance system to track social distance, wearing the mask, and body temperature [21][22].	5G for massive surveillance
5G/5G+	For continuous evaluation and monitoring of diabetic patients, a mobile health system based on 5G and IoT has been suggested. [23]	Remote medical assistance services
6G	A study on Optical biosensors has stated that the sensors can be used to measure the abnormal functioning of biorecognition molecules, including antibodies, enzymes, entire cells, and DNAzymes, in order to identify numerous illnesses more accurately [4].	Optical Biosensors for disease diagnosis.
6G	B5G framework uses the low-latency, high-bandwidth capability of the 5G network to identify COVID-19 utilizing chest X-ray or CT scan pictures and construct a massive surveillance system to track social distance, wearing the mask, and body temperature. [22].	Framework for assisting patients during Covid-19

communication, sensing, and localization, fulfilling the demands of the healthcare domain with a single system to work at lower costs.

The intelligent reference framework of the 6G technology for healthcare applications includes various layers like the storage layer, support layer, Intelligent Business layer, smart application layer, and smart sensor layer, for enabling the services like ultra-massive machine-type communications (umMTC) [36], extremely reliable and low latency communication (ERLLC) [37] and long-distance and

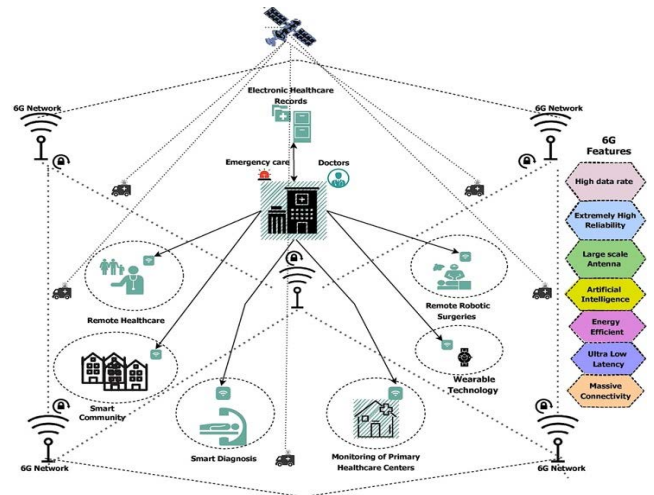


FIGURE 2. Healthcare applications integrated with over 6G technology.

high-mobility communications (LDHMC) [38] as presented in Figure 2. The terminal nodes and the networking nodes would work in coherence with the single system architecture for deliberating the services.

A. STORAGE LAYER

The storage layer in the reference framework is associated with various storage-related responsibilities and functionalities. The 6G technology can accommodate a tremendous amount of data on the fly through the distributed storage capabilities. Cooperation among numerous data stakeholders is required for 6G functionality, particularly users or machines for data production, data collection and transmission operators, and technology suppliers [39]. The layer's responsibilities include storage manager, data collection, pre-processing, data cleaning, data transformation, knowledge discovery, and Query processing to support intelligent data-driven and big-data-centric applications to function seamlessly.

B. SUPPORT LAYER

The support layer acts as the middleware among the intelligent algorithms that are part of the business and storage layers. The layer provides the services like a support platform for the applications, The technologies like fog/edge/cloud services are employed for data storage and processing, the security strategies like the blockchain, distributed ledger technologies, quantum encryption techniques, intelligent task scheduling, model optimization for better performance and by shifting heavy processing to edge servers, the protocol stack that could interface various services and guide the networking operations towards better efficiency.

C. INTELLIGENT BUSINESS LAYER

This layer of the proposed reference model holds amongst the most significant features of the 6G technology with responsibilities like Deep platform integration like cloudification, slicing, and softwarization [4], network operations, Cell-Less Networking [40], Dense Array device

handling algorithms that can withstand a large number of connected devices, Hyper intelligent algorithms for enhanced network operations, the intelligence of space things, and Mobile Edge Computing (MEC) [41] allows end devices to execute such low latency applications. Smart Application Layer: Smart application layer determines the purposed and the services rendered by the node in the network. The layers define the service models associated with various applications like Remote healthcare services, distributed services-centric applications, and Remote distributed architecture models, Automated services, and applications that rely on multiple inputs and outputs. This layer ensures collaborative working of divergent application service models to ensure time-aware responses to the costumers in the healthcare domain [42].

D. SMART SENSOR LAYER

The smart sensor layer deals with the physical sensing components used in perceiving and assisting the end-users in better operability. Various components encompass the layer for environmental monitoring, ambient technology, continuous monitoring, integration of wearable technology, surveillance, and active monitoring. Smart sensor layers are being used in applications like Ambient Assisted Living Environments [43], wearable technologies, Smart primary healthcare services, mobile frameworks for smart diagnosis [44], and smart integrated emergency ambulance services [45].

The layer in the reference frame is defined with the responsibilities that would assist the associated layers. The sensor and the actuators in real-time environments are part of the smart sensor layers. The data exchange and the service delivery are assisted through the layer above it. The 6G technology provides advanced intelligence services compared to its predecessors, delivered and managed by the intelligent business layer. The layered framework of the terminal and networking devices is presented in the subsequent sections of the study. The following is the algorithm that shows the algorithm for exchanging data in the network.

The data exchange is performed upon the availability of the data by taking the encryption keys and transaction identity (trans_id) into consideration. The data exchange is performed on successful authentication of the terminal devices and the availability of the data. The data is sent along with the key and the data offset to check the integrity of the transmitted information. The digital ledger is updated with the trans_id. The digital ledger would make data accessible and responsible to all network individuals. Decentralization prevents a single system attacker from safeguarding the system. It improves maintaining and accessing electronic health records and patient care by ensuring privacy and ease of access.

1) LAYER FRAMEWORK FOR TERMINAL DEVICES

The terminal devices are the end-use interactive components that provide end-user services, computational devices, Cellular phones, data acquisition gadgets, real-time sensing

Algorithm: Data Exchange Among Node

Input: data, data_offset, key, trans_id

Output: Boolean value (Success/failed) data exchange.

Begin:

```

while ( terminal_auth is true)
  if (data_available is false)
    throw;
  else
    update time_stamp;
    if (conet_net-node is successful)
      send [data, key, data_offset];
      update.ledger(trans_id);
      return true;
    else
      return false;
  end if else
end if else

```

End

components, and network actuators. The layered framework for terminal devices presents the services associated with each device to ensure time-sensitive and delay-efficient services. The framework for terminal devices consists of the Application interface later, the computing layer, and the infrastructure layer. These layers would collaboratively support the associated layer for seamless communication among the devices. The framework for terminal devices is presented in Figure 3.

a: INFRASTRUCTURE LAYER

The infrastructure layer consists of necessary resource-related services for better connectivity and services to the devices in the network. This layer promotes services like on-demand self-services, Air Interface, Quantum communication [46], and Rapid elasticity [47] like services for better communication of the devices in the healthcare domain.

b: COMPUTING LAYER

This layer performs the necessary computational activities to support the applications by acquiring support from the infrastructure layer. This layer delivers the services like service request generator, path management for ease of communication, resource discovery services, and the software-defined environment. The computational layers render the pivotal operational decisions and the related communication services. However, most computational services are disseminated by the cloud servers or the edge components.

c: APPLICATION INTERFACE LAYER

The interface layer is the interactive layer to the end-user, which delivers the services. The application layer provides the services like dynamic spectrum access, content-driven routing for fast and effective communication, intelligent controlling agent, and terminal application services like smart

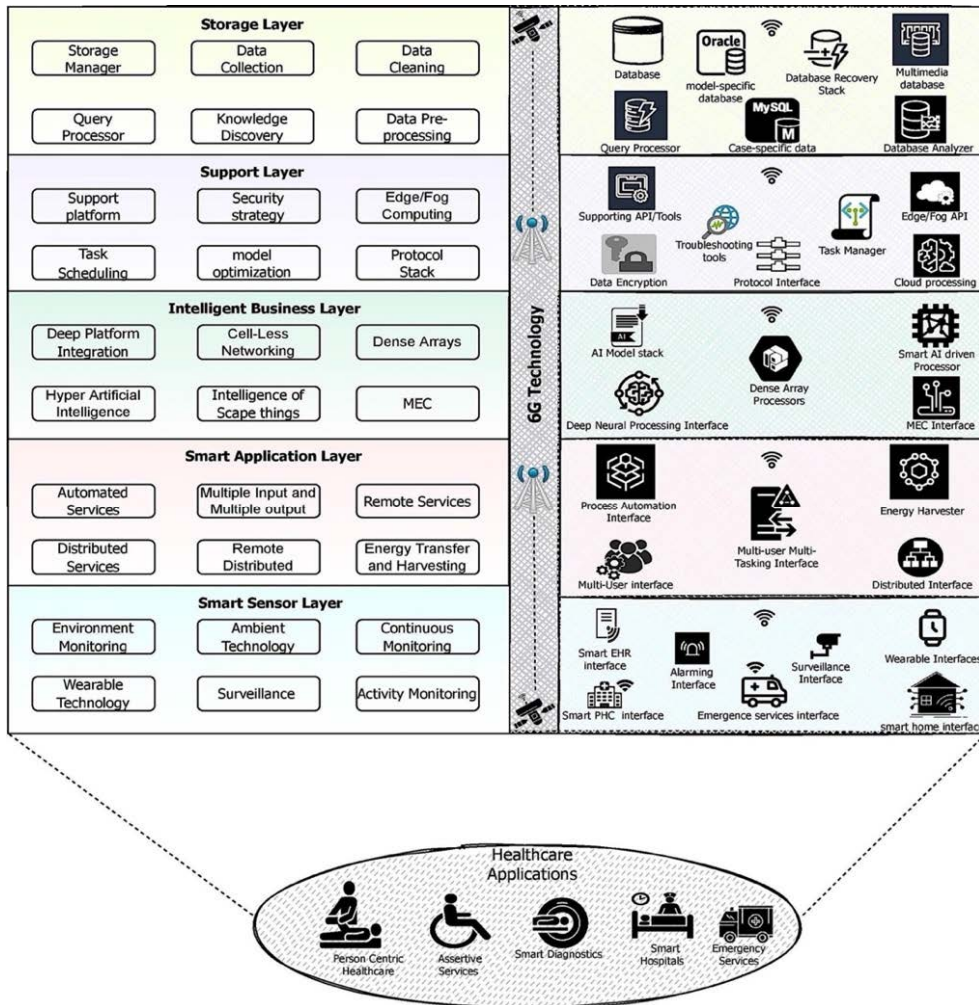


FIGURE 3. 6G framework for healthcare applications.

activity tracker, smart diagnostic tools, and a recommender system for wellbeing.

The following is the algorithm used to link the terminal nodes and update the routing information of the nodes in the network. The terminal nodes, which include the sensors nodes, wearable devices, surgical equipment, and robotic devices, are added based on the validity of the MAC address and the authentic credentials (Auth_Credentials). Upon successful validation, the node’s routing table is updated by assigning a network identity (network_id) to the device.

2) LAYER FRAMEWORK FOR NETWORKING DEVICES

The networking devices are the intermediate node in the network, acting as the media among the end-user devices like the computational devices and sensor nodes. The framework associated with networking devices is different from the terminal devices. The framework for the terminal nodes consists of layers like the services layer, control layer, and network interface layer. Figure 4 presents the layered framework for

the networking nodes in 6G for healthcare-related communications.

a: SERVICE LAYER

The service layer is responsible for providing various services to the networking devices like in-time and on-time services based on the type of delay-aware communication applications for which the services are provided. The other services include event-driven routing and controlling mechanisms and encryption services for the data exchanged through the networking device. This layer provides the necessary operational services to the control layer.

b: CONTROL LAYER

The control layer manages the services and deals with various network tasks and resource scheduling activities. The control layer deliberates the responsibilities like autonomic operations and maintenance, delay awareness, intelligent transmission, network resource management, task scheduling, and mobility management for the terminal devices in the network.

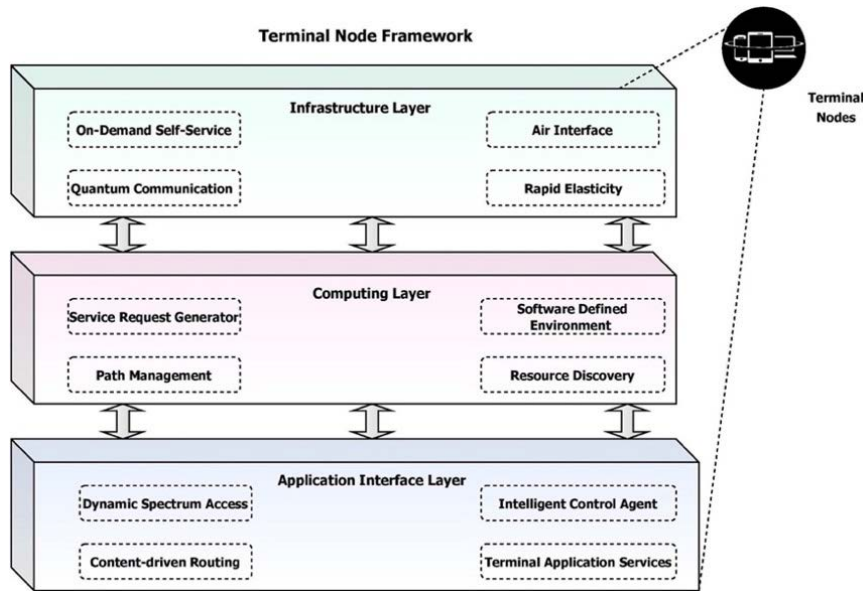


FIGURE 4. Layered framework for terminal nodes.

Algorithm: Linking Terminal Nod

Input: MAC address, Auth_Credentials
Output: Boolean Value (Accept/Reject) Routing table Updating.
Begin:
 if (req.terminal_MAC not in list)
 throw;
 if (req.terminal_node is not_auth)
 throw;
 else
 update(routing_table);
 assign(network_id);
 return true;
 end if else
end if
End

Apart from the responsibilities mentioned above, it also takes care of the energy of the networking devices for a longer lifetime.

c: NETWORK INTERFACE LAYER

The layer directly interacts with the networking components to perform routing and spectrum access tasks. It provides the services like content-driven routing and intelligent controlling agents for resource mapping, dynamic spectrum access, and terminal application services.

The following algorithms present the procedure for linking the networking node and updating the associated residual energy associated with the node.

In the process of updating the networking devices, which are part of the network. The process of linking the node is performed periodically after every time interval

Algorithm: Linking Networking Nod

Input: MAC address, Auth_Credentials, Availble_res-eng
Output: Boolean Value (Accept/Reject) Routing table Updating.
Begin:
 while (time_interval) **do**
 if (req.networking_MAC not in list)
 throw;
 if (req.networking is not_auth)
 throw;
 else
 update(routing_table);
 assign(node_id);
 flood res_eng;
 return true;
 end if else
 else
 update(routing_table);
 update(node_list);
 end if else
End

(time_interval). After successful MAC listing and the authentication, the nodes are updated in the routing table, and the residual energy information is flooded to the rest of the networking nodes in the network. If the authentication or the MAC address was not listed, the node was not linked to the network.

3) INTEGRATION OF REFERENCE FRAMEWORKS

The reference frameworks for the terminal devices in the real-time scenario and networking node are integrated through Services Program Interfaces (SPIs). SPI is a module of code

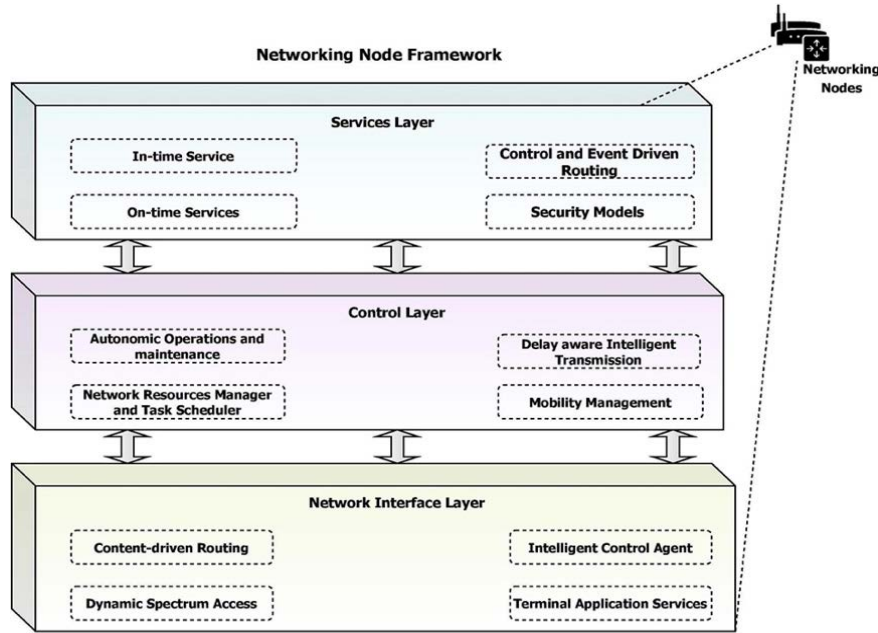


FIGURE 5. Layered framework for network nodes.

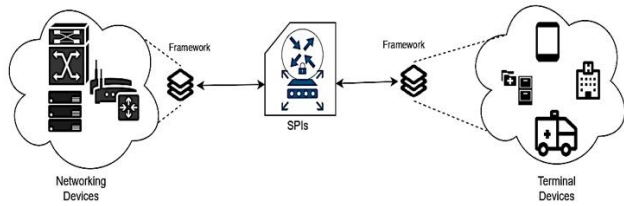


FIGURE 6. Image representing the role of SPI in integration.

that enables two components in the network to interact with one another. It specifies how a terminal node should seek services from a networking device or other application and disclose data in various contexts and through several channels. SPI makes the task of service models easier by allowing programs to communicate data and functions in a simple and safe manner. Figure 6 presents the role of SPI in integrating the reference framework.

IV. FUTURE PERSPECTIVES OF 6G IN HEALTHCARE

6G is anticipated as a technology that would enable wireless features in healthcare and the Internet of Bio-Nano-Things, enabling individuals to become a part of the web. This would assist every individual towards better livelihood by consistently monitoring them through sophisticated sensor technology, recommending better living habits, providing timely medication, and keeping them healthier. In the 6G technology, the healthcare recommender systems work more efficiently than the conventional technologies. The 6G combines multiple intelligence devices over an AI-driven network. It is expected to have a better Internet of Medical

Things (IoMT) over the future edge/fog/cloud computing technologies. A sample case study is being presented in the current section to better understand the future perspectives of the 6G technology.

A. CASE STUDY: REMOTE ROBOTIC SURGERY

Remote surgery is an advanced surgical procedure that uses a combination of robotic machines and networking technologies to link patients and doctors geographically apart to perform a remote surgical procedure. As a result of its capacity to overcome the limits of traditional surgery, telesurgery has become an appealing alternative for patients needing urgent and high-quality surgical treatment and a lack of surgeons and logistical constraints on surgeon schedules. There are few instances where a patient needs to be performed the surgical operation with the support of various specialty surgeons in a short period. In such a context, remote robotic surgical procedures make it feasible to connect the surgeons and physicians to perform a surgical operation collaboratively. The ultra-low network latency and hyper-connectivity of super-smart intelligent devices would make it feasible to perform remote robotic surgery with ease. Various such remote robotic operations have been performed in the recent past over the 5G technology, as presented in the study by Pandav k et al. [48]. Figure 7 below shows a group of surgeons who are geographically separate from performing surgery.

From the above figure, it could be seen that the doctors from various hospitals, namely A, B, C, D, and E, are collectively working to perform the robotic surgery where the information about his previous health care records is also integrated into the connection for ease of decision

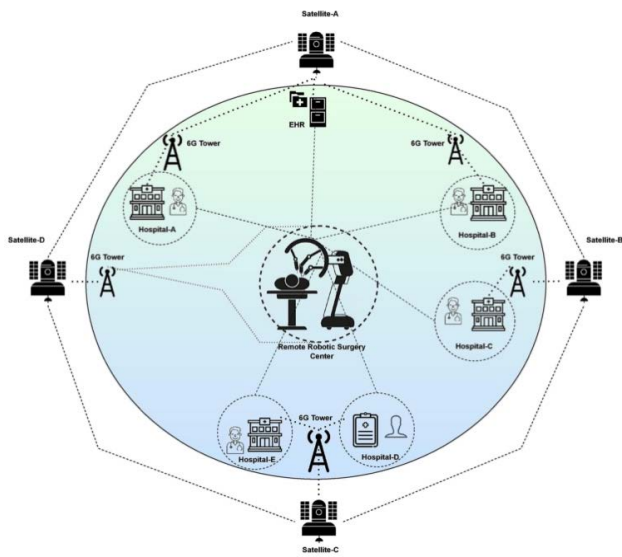


FIGURE 7. The layout of 6G-based remote robotic surgery.

making. The hospitals are connected to the cellular tower to exchange data over a 6G framework. The cellular tower directly interacts with the satellite, and the satellites communicate. Few studies have proven that robotic surgeries are performed with minimally invasive procedures than normal surgical operations [49]. The following scenario represents the surgical procedure for complex Aortic Arch Surgery (AAS) which needs specialized professionals such as the cardiac surgeon, thoracic surgeon, interventional radiologist, vascular surgeon, general physician, and anesthesiologist. For this surgical procedure, the role of every single specialist is exceedingly significant through the surgical procedure.

In figure 8, the role of the cardiac surgeon is to deal with the issues of the aortic root, and the vascular surgeons deal with the issues of decreasing the thoracic and abdominal aorta. The cardiac, vascular, and thoracic surgeons work collaboratively throughout the operational process. All of them are connected over the 6G framework for seamless communication. The robotic arms could be controlled remotely, and the surgeons can perform the operations without any network dependencies to deal with divergent devices. The general physician would start the treatment process, and then the anesthesiologist would join the surgical procedure and initiate the treatment process by giving the local/global anesthesia. The interventional radiologist would localize the region of interest to initiate the repair of the Aortic arch. The Thoracic, vascular, and cardiac surgeon is collaboratively done the repairing procedure. Finally, the interventional radiologist would close the opening and stitch back the body.

The following are the services program interfaces that integrate multiple connections to work in line at ultra-low latency and deliberate the reliable services for those robotic surgeries. A few SPIs involve connection scheduler, resource switching,

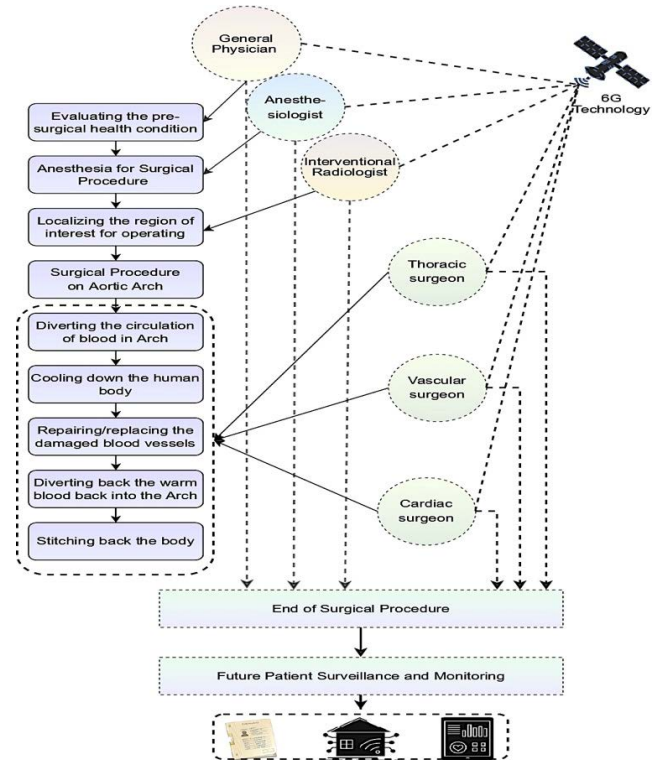


FIGURE 8. The surgical workflow for robotic aortic arch surgery over the 6G Technology.

Compliance Control, Kinematics controller, Teleoperation, and Delay Handler.

Connection Scheduler: There are multiple connections simultaneously, and the primary channel that operates for that instance would be allotted with the designated resources, and the connection switching from the channel to channel throughout the surgical process was taken care of by the connection scheduler. The session management will also be taken care of by the scheduler.

Resource Switching: The resource scheduler cooperates with the connection scheduler in allocating the resources to the primary channel on a master-slave basis for all the integrated channels performing the remote surgical procedure. Access to the EHR and local environment is also being taken care of by the resource scheduler.

Priority Manager: It is an exceptionally important SPI to handle multiple requests and jobs simultaneously in a strained environment. e priority manager takes care of the responsibilities like resource allocation and the primary channel switching.

Compliance Control: In the communication process, there are divergent nodes that would be involved in the communication process, and each of them might have its proprietary frameworks for communication. The Compliance Control would act as the interface among the divergent nodes to communicate seamlessly.

Kinematics controller: It is responsible for handling services such as constrained optimization that concurrently

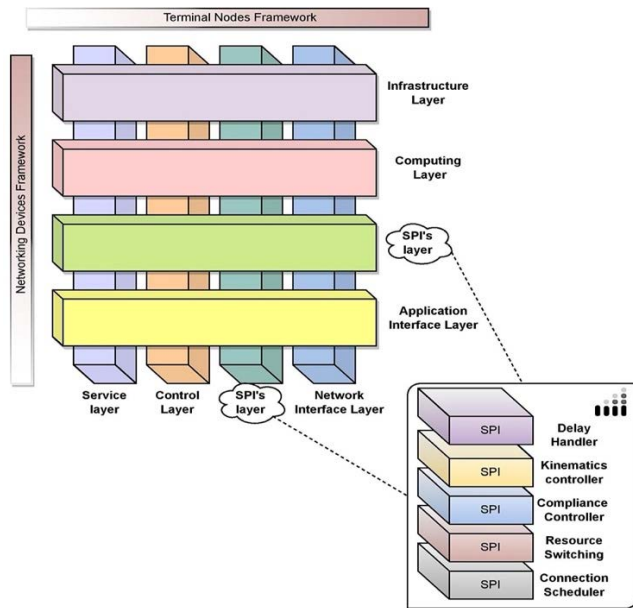


FIGURE 9. Layered framework integration over the SPI.

solves kinematics and control for applications such as kinematic redundancy optimization and virtual fixture enforcement that would largely assist during the surgical process.

Teleoperation: It supports teleoperation over several communication channels, with various master and slave devices, and includes bilateral teleoperation among the surgeons and supporting staff while performing the remote robotic surgeries.

Delay Handler: The surgical procedures are extremely time sensitive, and 6G technology is calibrated to provide the services at ultra-low latency. Yet, there might be some external factors that might lead to unexpected delays in communication. The delay handle is responsible for such situations to ensure timely services during the surgical process. Figure 9 presents the integration framework of SPIs among the terminal devices and the networking nodes.

V. 6G AND HEALTHCARE DOMAIN: POTENTIAL CHALLENGES ADDRESSED

The 6G technology has potential limitations like the security and the privacy factors associated with the network, the cost of establishing and maintaining the network, and the health impact of the 6G technology on humans. There are a few ways to summarize the service and application's challenges in the current scenario where the 6G technology must gear up to address them. A few of those challenges are as follows. There will be a greater variety of service and application needs than ever before; To provide a more immersive user experience, it is necessary to orchestrate and configure the end-to-end network on-demand for customized and personalized services. The combination of communication, computation and sensing enhances services and business cases. Rather than relying

Algorithm: Data and Network Handler Interfac

Input: MAC address, Service_List, Auth_Credentials, Available_res-eng, session_id Node_id, Channel_id, List_SPI

Output: Boolean Value (Accept/Reject) service request.

Begin:

while (true) **do**

Create new_job-handler

thread.delay_handler();

thread.kinematics-controller();

thread.compliance-controller();

thread.resource-switching();

thread.connection-scheduler();

thread.priority-manager();

return job-handler_id;

if (req.connection is not_auth)

throw;

else

verify(session_id); // if true;

assign(priority_id); // if true;

check(resource_demand) // if avail;

return true;

end if else

compliance-controller();

priority-manager();

allot connection_id;

If (match.channel_id)

Assign resources_block;

Exchange_data();

End if

End

on patched assistance, service providers now expect more efficient and effective security support [50], [51], [52], [53].

A. NETWORK LATENCY ISSUES

It is desired to have a minimal computational delay for dealing with devices and sensors used in the healthcare domain. Networking components and smart healthcare devices collaborate, especially in remote surgeries, robotic-assisted medication, and ambient-assisted environments. 6G technology is desired to provide ultra-low latency compared to previous-generation technologies. This enables the network to do more by managing and reacting to external stimuli more effectively and quickly [54].

B. NETWORK BANDWIDTH ISSUES

The number of devices that rely on wireless technology is ever-growing, and it is desired to have sustainable bandwidth for seamless communication. It is desired to assist the smart healthcare applications in 6G with the support of machine intelligence and edge technologies in effectively utilizing heterogeneous networks with enormous antennas equipped

with intelligent channel allocation mechanisms, with wider bandwidth to offer diverse services.

C. NETWORK SECURITY CONSTRAINTS

The most significant network concerns are information processing, threat intelligence and identification, network monitoring, traffic analysis, and data encryption strategies. The blockchain, distributed ledger technologies, and Quantum security capabilities will ensure the confidentiality and the integrity of sensitive healthcare data. Quantum Machine Learning algorithms can potentially improve network privacy and security [32].

D. NETWORK COMPUTATIONAL CAPABILITIES

A significant driver of 6G is the requirement to install cloud/fog/edge computing to provide higher throughput and lower network latency delays for energy-aware ultra-reliable intelligent communications applications. During the 6G transition, core network equipment will be outfitted with computational and caching capacity. Furthermore, 6G will offer an intelligent interconnection of nodes by leveraging the terminal, network, and centralized information to improve operational performance.

E. NETWORK OPENNESS

The Network device should facilitate the interoperability of divergent end-systems and the flexible scheduling of disseminated network segments. 6G will feature service-driven heterogeneous network management, allowing network operators and specialized industries to deploy new services rapidly. The openness of the connecting interface is utilized to promote better interconnection and interoperability of multiple networking devices seamlessly, which is critical for the pooling of infrastructure facilities and the development of the mobile network ecosystem [55].

F. CELL-FREE ACCESS NETWORKS

Users connecting to an access point (gNB) outside of a cell will be referred to as cell-less architecture, the revolutionary feature of 6G technology, which is a novel concept in future network design. When you use this service, users do not have to worry about the restrictions imposed by cell boundaries. Moreover, Changes in cell search strategies, synchronization, and random access must be made to accommodate the new cell-less approach.

G. ENERGY-EFFICIENT COMMUNICATION

The 6G networks are efficient in energy-aware communication among the devices in the network. The energy-aware algorithms are promoted a longer lifetime for the associated sensor nodes in the network. Spectral efficiency is another aspect that enriches the effective energy utilization for communication. 6G transmitters are predicted to offer great energy efficiency and new spectrum technical standards to handle difficulties like network designs, testing ground development, physical layer deliveries, and privacy [56].

H. CELLULAR COVERAGE

Because of several reasons, seamless coverage and connection are necessary for all situations in healthcare systems. Because of the hospital's complicated spatial form and attached devices, network coverage is restricted. In this regard, aerial networks, notably UAVs, HAPs, and satellites, are among the most promising prospects for coverage expansion. These networks may improve coverage by serving as base stations or relay transceivers [45], [57].

I. LOCALIZATION AND PRECISE POSITIONING

Indoor and outdoor locations might be critical in providing a quick reaction during emergencies such as natural catastrophes. The global positioning system may be used for outdoor tracking and localization like GPS. However, owing to the complicated electromagnetic propagation environment, GPS cannot give reliable inside location. When hospitals become overloaded with people after a crisis, locating physicians, medical personnel, and patients become more difficult. Locating medical workers and patients enabled with real-time coordination and fast response for essential patients may be accomplished with a real-time location system over the 6G architecture [58], [59].

J. EDGE INTELLIGENCE AND FOG COMPUTING

In the healthcare sector, the information about all the stakeholders like the patients and doctors are remotely stored over the cloud. Data generated by intelligent devices is sent to the cloud for storage, but this uses channel access and bandwidth. 6G claims to offer a great capacity for providing seamless service to millions of smart devices. 6G will depend on Edge technology to deliver seamless and fast Internet access to intelligent devices, which is critical in healthcare. In its Edge nodes, Edge technology gathers, computes, and analyses medical information in real-time [9], [60].

The 5G and advanced 5G technology like 5G+ have some the mutations like coverage and the mobility of the devices, and intelligence in the devices in functional integration and deliberating the services. The limitations like data rate, latency, spectrum, and bandwidth have challenged most of the time-sensitive and resource-aware services in the healthcare sector [61].

VI. CONCLUSION

This paper outlines the divergent healthcare applications and their associated potential challenges overcome by 6G technology. It is desired to have a single system reference model that integrates the operations and services seamlessly among the divergent applications used in the healthcare domain. The generic framework for integrating terminal, networking nodes, and layer framework are discussed. The future perspective section discusses the influence of 6G technology in future healthcare applications. A case study on aortic arch surgery would assist in better comprehensibility of futuristic applications over 6G technology in healthcare. The fusion of Artificial Intelligence and 6G communication networks will usher in a new age in smart healthcare technologies.

In future work, we will consider evaluating the proposed framework over the metrics like lifetime, throughput, and latency considered in a simulating environment by integrating the nodes and exchanging the data. And working with more such application specific case studies would assist in customizing the generic framework to ensure the QoS.

ACKNOWLEDGMENT

Jana Shafi would like to thank the Deanship of Scientific Research, Prince Sattam bin Abdul Aziz University, for supporting this work.

REFERENCES

- [1] J. R. Bhat and S. A. Alqahtani, "6G ecosystem: Current status and future perspective," *IEEE Access*, vol. 9, pp. 43134–43167, 2021, doi: [10.1109/ACCESS.2021.3054833](https://doi.org/10.1109/ACCESS.2021.3054833).
- [2] T. Huang, W. Yang, J. Wu, J. Ma, X. Zhang, and D. Zhang, "A survey on green 6G network: Architecture and technologies," *IEEE Access*, vol. 7, pp. 175758–175768, 2019.
- [3] C. Herranz, M. Zhang, M. Mezzavilla, D. Martin-Sacristán, S. Rangan, and J. F. Monserrat, "A 3GPP NR compliant beam management framework to simulate end-to-end mmWave networks," in *Proc. 21st ACM Int. Conf. Model., Anal., Simul. Wireless Mobile Syst.*, 2018, pp. 119–125.
- [4] M. W. Akhtar, S. A. Hassan, R. Ghaffar, H. Jung, S. Garg, and M. S. Hossain, "The shift to 6G communications: Vision and requirements," *Hum.-Centric Comput. Inf. Sci.*, vol. 10, no. 1, pp. 1–27, Dec. 2020.
- [5] C. Sergiou, M. Lestas, P. Antoniou, C. Liaskos, and A. Pitsillides, "Complex systems: A communication networks perspective towards 6G," *IEEE Access*, vol. 8, pp. 89007–89030, 2020.
- [6] H. Kim, "Enhanced mobile broadband communication systems," in *Design and Optimization for 5G Wireless Communications*, H. Kim, Ed. Hoboken, NJ, USA: Wiley, 2020, pp. 239–302, doi: [10.1002/9781119494492.ch7](https://doi.org/10.1002/9781119494492.ch7).
- [7] P. Popovski, J. J. Nielsen, C. Stefanovic, E. de Carvalho, E. Strom, and K. F. Trillingsga, "Wireless access for ultra-reliable low-latency communication: Principles and building blocks," *IEEE Netw.*, vol. 32, no. 2, pp. 16–23, Mar./Apr. 2018, doi: [10.1109/MNET.2018.1700258](https://doi.org/10.1109/MNET.2018.1700258).
- [8] M. R. Chowdhury and S. De, "Queue-aware access prioritization for massive machine-type communication," *IEEE Internet Things J.*, vol. 9, no. 17, pp. 15858–15873, Sep. 2022, doi: [10.1109/JIOT.2022.3151408](https://doi.org/10.1109/JIOT.2022.3151408).
- [9] M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *IEEE Open J. Commun. Soc.*, vol. 1, pp. 957–975, 2020, doi: [10.1109/OJCOMS.2020.3010270](https://doi.org/10.1109/OJCOMS.2020.3010270).
- [10] W. Saad, M. Bennis, and M. Chen, "A vision of 6G wireless systems: Applications, trends, technologies, and open research problems," *IEEE Netw.*, vol. 34, no. 3, pp. 134–142, May 2019, doi: [10.1109/MNET.001.1900287](https://doi.org/10.1109/MNET.001.1900287).
- [11] H. Chergui, L. Blanco, L. A. Garrido, and K. Ramantas, "Zero-touch AI-driven distributed management for energy-efficient 6G massive network slicing," *IEEE Netw.*, vol. 35, no. 6, pp. 43–49, Nov./Dec. 2021, doi: [10.1109/MNET.111.2100322](https://doi.org/10.1109/MNET.111.2100322).
- [12] J. Marescaux, J. Leroy, F. Rubino, M. Smith, M. Vix, M. Simone, and D. Mutter, "Transcontinental robot-assisted remote telesurgery: Feasibility and potential applications," *Ann. Surgery*, vol. 235, no. 4, pp. 487–492, 2002.
- [13] S. Nayak and R. Patgiri, "6G communication technology: A vision on intelligent healthcare," in *Health Informatics: A Computational Perspective in Healthcare* (Studies in Computational Intelligence), vol. 932, R. Patgiri, A. Biswas, and P. Roy, Eds. Singapore: Springer, 2021.
- [14] T. Xie, M. Ge, and S. L. Lu, "Exploration on the linkage between wound healing department and community health system," *Chin. J. Burns*, vol. 27, pp. 43–44, Feb. 2011.
- [15] I. U. Rehman, N. Y. Philip, and R. S. H. Istepanian, "Performance analysis of medical video streaming over 4G and beyond small cells for indoor and moving vehicle (ambulance) scenarios," in *Proc. 4th Int. Conf. Wireless Mobile Commun. Healthcare Transforming Healthcare Through Innov. Mobile Wireless Technol. (MOBIHEALTH)*, 2014, pp. 211–216, doi: [10.4108/icst.mobihealth.2014.257415](https://doi.org/10.4108/icst.mobihealth.2014.257415).
- [16] K. E. Georgiou, E. Georgiou, and R. M. Satava, "5G use in healthcare: The future is present," *J. Soc. Laparoscopic Robotic Surgeons*, vol. 25, no. 4, Oct. 2021, Art. no. e2021.00064, doi: [10.4293/JLSLS.2021.00064](https://doi.org/10.4293/JLSLS.2021.00064).
- [17] A. Angelucci, D. Kuller, and A. Alivertim, "A home telemedicine system for continuous respiratory monitoring," *IEEE J. Biomed. Health Inform.*, vol. 25, no. 4, pp. 1247–1256, Apr. 2020.
- [18] R. Ye, X. Zhou, and F. Shao, "Feasibility of a 5G-based robot-assisted remote ultrasound system for cardiopulmonary assessment of patients with coronavirus disease 2019," *Chest*, vol. 159, no. 1, pp. 270–281, 2021.
- [19] L. B. Valdez, R. R. Datta, B. Babic, and D. T. Müller, "5G mobile communication applications for surgery: An overview of the latest literature," *Artif. Intell. Gastrointestinal Endoscopy*, vol. 2, no. 1, pp. 1–11, 2021.
- [20] A. M. Lacy, R. Bravo, and A. M. Otero-Piñeiro, "5G-assisted telemonitored surgery," *Brit. J. Surg.*, vol. 106, no. 12, pp. 1576–1579, 2019.
- [21] A. I. Abubakar, K. G. Omeke, M. Ozturk, S. Hussain, and M. A. Imran, "The role of artificial intelligence driven 5G networks in COVID-19 outbreak: Opportunities, challenges, and future outlook," *Frontiers Commun. Netw.*, vol. 1, Nov. 2020, Art. no. 575065, doi: [10.3389/frcom.2020.575065](https://doi.org/10.3389/frcom.2020.575065).
- [22] M. S. Hossain, G. Muhammad, and N. Guizani, "Explainable AI and mass surveillance system-based healthcare framework to combat COVID-19 like pandemics," *IEEE Network*, vol. 34, no. 4, pp. 126–32, Jul. 2020, pp. 1–7, doi: [10.1109/MNET.011.2000458](https://doi.org/10.1109/MNET.011.2000458).
- [23] M. Chen, J. Yang, J. Zhou, Y. Hao, J. Zhang, and C. H. Youn, "5G-smart diabetes: Toward personalized diabetes diagnosis with healthcare big data clouds," *IEEE Commun. Mag.*, vol. 56, no. 4, pp. 16–23, Apr. 2018.
- [24] S. N. Nova, M. S. Rahman, and C. Chakraborty, "Patient's health surveillance model using IoT and 6G technology," in *Green Technological Innovation for Sustainable Smart Societies*, C. Chakraborty, Ed. Cham, Switzerland: Springer, 2021, pp. 191–209.
- [25] D. C. Nguyen, M. Ding, P. N. Pathirana, A. Seneviratne, J. Li, D. Niyato, O. Dobre, and H. V. Poor, "6G Internet of Things: A comprehensive survey," *IEEE Internet Things J.*, vol. 9, no. 1, pp. 359–383, Jan. 2022, doi: [10.1109/JIOT.2021.3103320](https://doi.org/10.1109/JIOT.2021.3103320).
- [26] P. N. Srinivasu, G. JayaLakshmi, R. H. Jhaveri, and S. P. Praveen, "Ambient assistive living for monitoring the physical activity of diabetic adults through body area networks," *Mobile Inf. Syst.*, vol. 2022, Apr. 2022, Art. no. 3169927.
- [27] S. A. Abdel Hakeem, H. H. Hussein, and H. Kim, "Vision and research directions of 6G technologies and applications," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 34, no. 6, pp. 2419–2442, Jun. 2022.
- [28] M. Noor-A-Rahim, Z. Liu, H. Lee, M. O. Khyam, J. He, D. Pesch, K. Moessner, W. Saad, and H. V. Poor, "6G for vehicle-to-everything (V2X) communications: Enabling technologies, challenges, and opportunities," *Proc. IEEE*, vol. 110, no. 6, pp. 712–734, Jun. 2022, doi: [10.1109/JPROC.2022.3173031](https://doi.org/10.1109/JPROC.2022.3173031).
- [29] L. Mucchi, S. Jayousi, S. Caputo, E. Paoletti, P. Zoppi, S. Geli, and P. Dioniso, "How 6G technology can change the future wireless healthcare," in *Proc. 2nd 6G Wireless Summit (6G SUMMIT)*, 2020, pp. 1–6.
- [30] T. Saedi, S. N. Mahmood, S. Alani, S. M. Ali, I. Ismail, and A. R. Alhawari, "Sub-6G metamaterial-based flexible wearable UWB antenna for IoT and WBAN," in *Proc. IEEE Intl Conf. Dependable, Autonomic Secure Comput., Intl Conf. Pervasive Intell. Comput., Intl Conf. Cloud Big Data Comput., Intl Conf. Cyber Sci. Technol. Congr.*, Aug. 2020, pp. 7–13.
- [31] W. Z. Khan, M. H. Rehman, H. M. Zangoti, M. K. Afzal, N. Armi, and K. Salah, "Industrial Internet of things: Recent advances, enabling technologies and open challenges," *Comput. Elect. Eng.*, vol. 81, Jan. 2020, Art. no. 106522.
- [32] M. Kumar, Kavita, S. Verma, A. Kumar, M. F. Ijaz, and D. B. Rawat, "ANAF-IoMT: A novel architectural framework for IoMT enabled smart healthcare system by enhancing security based on RECC-VC," *IEEE Trans. Ind. Informat.*, early access, Jun. 14, 2022, doi: [10.1109/TII.2022.3181614](https://doi.org/10.1109/TII.2022.3181614).
- [33] E. Sahin, O. Dageviren, and M. A. Akkas, "An evaluation of Internet of Nano-things simulators," in *Proc. 6th Int. Conf. Comput. Sci. Eng. (UBMK)*, 2021, pp. 670–675, doi: [10.1109/UBMK52708.2021.9558990](https://doi.org/10.1109/UBMK52708.2021.9558990).
- [34] H. H. Hussein and S. M. Abd El-Kader, "Enhancing signal to noise interference ratio for device to device technology in 5G applying mode selection technique," in *Proc. Intl Conf. Adv. Control Circuits Syst. (ACCS) Syst. Intl Conf. New Paradigms Electron. Inf. Technol. (PEIT)*, 2017, pp. 187–192.
- [35] A. Gupta, X. Fernando, and O. Das, "Reliability and availability modeling techniques in 6G IoT networks: A taxonomy and survey," in *Proc. Int. Wireless Commun. Mobile Comput. (IWCMC)*, 2021, pp. 586–591, doi: [10.1109/IWCMC51323.2021.9498628](https://doi.org/10.1109/IWCMC51323.2021.9498628).

- [36] K. Binod, O. L. A. López, H. Alves, and M. Latva-Aho, "Ultra-reliable communication for critical machine type communication via cran-enabled multi-connectivity diversity schemes," *Sensors*, vol. 21, no. vol. 23, p. 8064, 2021.
- [37] S. Mumtaz, V. G. Menon, and M. I. Ashraf, "Guest editorial: Ultra-low-latency and reliable communications for 6G networks," *IEEE Commun. Standards Mag.*, vol. 5, no. 2, pp. 10–11, Jun. 2021, doi: [10.1109/MCOM-STD.2021.9464926](https://doi.org/10.1109/MCOM-STD.2021.9464926).
- [38] W. Long, R. Chen, M. Moretti, W. Zhang, and J. Li, "A promising technology for 6G wireless networks: Intelligent reflecting surface," *J. Commun. Inf. Netw.*, vol. 6, no. 1, pp. 1–16, Mar. 2021, doi: [10.23919/JCIN.2021.9387701](https://doi.org/10.23919/JCIN.2021.9387701).
- [39] X. Shen, D. Liu, C. Huang, L. Xue, H. Yin, W. Zhuang, R. Sun, and B. Ying, "Blockchain for transparent data management toward 6G," *Engineering*, vol. 8, pp. 74–85, Jan. 2022.
- [40] K. David, A. Al-Dulaimi, H. Haas, and R. Q. Hu, "6G networks: Is this an evolution or a revolution? [From the guest editors]," *IEEE Veh. Technol. Mag.*, vol. 16, no. 4, pp. 14–15, Dec. 2021.
- [41] Y. Zhang, "Mobile edge computing for beyond 5G/6G," in *Mobile Edge Computing, Simula SpringerBriefs on Computing*, vol. 9. Cham, Switzerland: Springer, 2022.
- [42] A. Moubayed, A. Shami, and A. Al-Dulaimi, "On end-to-end intelligent automation of 6G Networks," *Future Internet*, vol. 14, no. 6, p. 165, 2022, doi: [10.3390/fi14060165](https://doi.org/10.3390/fi14060165).
- [43] C. Sandeepa, C. Moremada, N. Dissanayaka, T. Gamage, and M. Liyanage, "An emergency situation detection system for ambient assisted living," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, May 2020, pp. 1–6, doi: [10.1109/ICCWorkshops49005.2020.9145053](https://doi.org/10.1109/ICCWorkshops49005.2020.9145053).
- [44] A. Vulli, P. N. Srinivasu, M. S. K. Sashank, J. Shafi, J. Choi, and M. F. Ijaz, "Fine-tuned DenseNet-169 for breast cancer metastasis prediction using fastAI and 1-cycle policy," *Sensors*, vol. 22, no. 8, p. 2988, Apr. 2022.
- [45] M. B. Janjua, A. E. Duranay, and H. Arslan, "Role of wireless communication in healthcare system to cater disaster situations under 6G vision," *Frontiers Commun. Netw.*, vol. 1, Dec. 2020, Art. no. 610879.
- [46] S. J. Nawaz, S. K. Sharma, S. Wyne, M. N. Patwary, and M. Asaduzzaman, "Quantum machine learning for 6G communication networks: State-of-the-art and vision for the future," *IEEE Access*, vol. 7, pp. 46317–46350, 2019.
- [47] P. K. Padhi and F. Charrua-Santos, "6G enabled tactile internet and cognitive Internet of Healthcare everything: Towards a theoretical framework," *Appl. Syst. Innov.*, vol. 4, no. 3, p. 66, 2021.
- [48] K. Pandav, A. G. Te, N. Tomer, S. S. Nair, and A. K. Tewari, "Leveraging 5G technology for robotic surgery and cancer care," *Cancer Rep.*, vol. 5, no. 8, p. e1595, 2022, doi: [10.1002/cnr2.1595](https://doi.org/10.1002/cnr2.1595).
- [49] P. N. Srinivasu, A. K. Bhoi, R. H. Jhaveri, G. T. Reddy, and M. Bilal, "Probabilistic deep q network for real-time path planning in censorious robotic procedures using force sensors," *J. Real-Time Image Process.*, vol. 18, no. 5, pp. 1773–1785, Oct. 2021.
- [50] G. Liu, N. Li, J. Deng, Y. Wang, J. Sun, and Y. Huang, "The SOLIDS 6G mobile network architecture: Driving forces, features, and functional topology," *Engineering*, vol. 8, pp. 42–59, Jan. 2022.
- [51] M. M. Aslam, L. Du, X. Zhang, Y. Chen, Z. Ahmed, and B. Qureshi, "Sixth generation (6G) cognitive radio network (CRN) application, requirements, security issues, and key challenges," *Wireless Commun. Mobile Comput.*, vol. 2021, Oct. 2021, Art. no. 1331428.
- [52] L. U. Khan, I. Yaqoob, M. Imran, Z. Han, and C. S. Hong, "6G wireless systems: A vision, architectural elements, and future directions," *IEEE Access*, vol. 8, pp. 147029–147044, 2020.
- [53] A. Vergütz, G. N. Prates, Jr., S. B. Henrique, A. Santos, and M. Nogueira, "An architecture for the performance management of smart healthcare applications," *Sensors*, vol. 20, no. 19, p. 5566, 2020, doi: [10.3390/s20195566](https://doi.org/10.3390/s20195566).
- [54] G. Alfian, M. Syafrudin, I. MF, S. MA, F. NL, and J. A. Rhee, "Personalized healthcare monitoring system for diabetic patients by utilizing BLE-based sensors and real-time data processing," *Sensors*, vol. 18, no. 7, p. 2183, 2018, doi: [10.3390/s18072183](https://doi.org/10.3390/s18072183).
- [55] Y. Zhou, L. Liu, L. Wang, N. Hui, X. Cui, J. Wu, Y. Peng, Y. Qi, and C. Xing, "Service-aware 6G: An intelligent and open network based on the convergence of communication, computing and caching," *Digit. Commun. Netw.*, vol. 6, no. 3, pp. 253–260, Aug. 2020.
- [56] A. H. Sodhro, S. Pirbhulal, Z. Luo, K. Muhammad, and N. Z. Zahid, "Toward 6G architecture for energy-efficient communication in IoT-enabled smart automation systems," *IEEE Internet Things J.*, vol. 8, no. 7, pp. 5141–5148, Apr. 2021.
- [57] H. Sameddeen, N. Saeed, T. Y. Al-Naffouri, and M.-S. Alouini, "Next generation terahertz communications: A rendezvous of sensing, imaging, and localization," *IEEE Commun. Mag.*, vol. 58, no. 5, pp. 69–75, May 2020, doi: [10.1109/MCOM.001.1900698](https://doi.org/10.1109/MCOM.001.1900698).
- [58] F. Mogyorósi, P. Revisnyei, A. Pašić, Z. Papp, I. Törös, P. Varga, and A. Pašić, "Positioning in 5G and 6G networks—A Survey," *Sensors*, vol. 22, no. 13, p. 4757, 2022, doi: [10.3390/s22134757](https://doi.org/10.3390/s22134757).
- [59] M. Säily, O. N. C. Yilmaz, D. S. Michalopoulos, E. Pérez, R. Keating, and J. Schaepperle, "Positioning technology trends and solutions toward 6G," in *Proc. IEEE 32nd Annu. Int. Symp. Pers., Indoor Mobile Radio Commun. (PIMRC)*, Sep. 2021, pp. 1–7, doi: [10.1109/PIMRC50174.2021.9569341](https://doi.org/10.1109/PIMRC50174.2021.9569341).
- [60] B. Mao, Y. Kawamoto, and N. Kato, "AI-based joint optimization of QoS and security for 6G energy harvesting Internet of Things," *IEEE Internet Things J.*, vol. 7, no. 8, pp. 7032–7042, Aug. 2020.
- [61] X. You, C. X. Wang, J. Huang, X. Gao, and Z. Zhang, "Towards 6G wireless communication networks: Vision, enabling technologies, and new paradigm shifts," *Sci. China Inf. Sci.*, vol. 64, 2011, Art. no. 110301, doi: [10.1007/s11432-020-2955-6](https://doi.org/10.1007/s11432-020-2955-6).



PARVATHANENI NAGA SRINIVASU received the bachelor's degree in computer science engineering from the SSIET, JNTU Kakinada, in 2011, and the master's degree in computer science technology and the Ph.D. degree for his thesis entitled "An Investigative Analysis of Automated Segmentation Approaches for Volumetric Estimation of Damaged Regions in Astrocytoma Cases Identified from the 2D Brain MR Image" from the GITAM University, Visakhapatnam, India, in

2013 and 2020, respectively. He is currently an Associate Professor with the Department of Computer Science and Engineering, Prasad V. Potluri Siddhartha Institute of Technology. As part of their research endeavors, numerous publications are made in reputed journals, and he has edited various books with publishers like Elsevier, Springer, IGI Global, and Bentham Science. His research interests include biomedical imaging, soft computing, sensor networks, and healthcare informatics.



MUHAMMAD FAZAL IJAZ (Member, IEEE) received the B.Eng. degree in industrial engineering and management from the University of the Punjab, Lahore, Pakistan, in 2011, and the Dr.Eng. degree in industrial and systems engineering from Dongguk University, Seoul, South Korea, in 2019. From 2019 to 2020, he worked as an Assistant Professor with the Department of Industrial and Systems Engineering, Dongguk University. He is currently working as an Assistant Professor with

the Department of Intelligent Mechatronics Engineering, Sejong University, Seoul, South Korea. He has published numerous research articles in several international peer-reviewed journals, including *Scientific Reports*, *IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS*, *IEEE ACCESS*, *Sensors*, *Journal of Food Engineering*, *Applied Sciences*, and *Sustainability*. His research interests include machine learning, blockchain, healthcare engineering, the Internet of Things, big data, and data mining.



JANA SHAFI is currently affiliated with the Department of Computer Science, Prince Sattam bin Abdulaziz University, Saudi Arabia. She has more than eight years of teaching and research experience. She has published in numerous journals, such as *Sensors*, *IEEE ACCESS*, *Diagnostics*, *Symmetry*, *Mathematics*, and *Wireless Communications and Mobile Computing*. Her research interests include online social networks, wearable technology, artificial intelligence, machine learning, deep learning, smart health, and the IoMT.



MARCIN WOŹNIAK received the M.Sc. degree in applied mathematics, the Ph.D. degree in computational intelligence, and the D.Sc. degree in computational intelligence. He was a Visiting Researcher with universities in Italy, Sweden, and Germany. He is currently an Associate Professor with the Faculty of Applied Mathematics, Silesian University of Technology. He is a Scientific Supervisor in editions of “The Diamond Grant” and “The Best of the Best” Programs for highly talented students from the Polish Ministry of Science and Higher Education. He participated in various scientific projects (a lead investigator, a scientific investigator, a manager, a participant, and an advisor) at Polish, Italian, and Lithuanian universities and projects with applied results in IT industry. He has authored/coauthored over 200 research papers in international conferences and journals. His current research interest includes neural networks with their applications together with various aspects of applied computational intelligence accelerated by evolutionary computation and federated learning models. In 2017, the Polish Ministry of Science and Higher Education awarded him a scholarship for an Outstanding Young Scientist. In 2021, he received an Award from the Polish Ministry of Science and Higher Education for research achievements. In 2020 and 2021, he was presented among “Top 2% Scientists in the World” by Stanford University for his career achievements. He is a Session Chair at various international conferences and symposiums, including the IEEE Symposium Series on Computational Intelligence and the IEEE Congress on Evolutionary Computation. He was the Editorial Board Member or an Editor of *Sensors*, *IEEE ACCESS*, *Measurement*, *Sustainable Energy Technologies and Assessments*, *Frontiers in Human Neuroscience*, *PeerJ CS*, *International Journal of Distributed Sensor Networks*, *Computational Intelligence and Neuroscience*, and *Journal of Universal Computer Science*.



R. SUJATHA received the B.E. degree in computer science from Madras University, in 2001, the Master of Financial Management degree from Pondicherry University, in 2005, the M.E. degree (Hons.) in computer science from Anna University, in 2009, and the Ph.D. degree in the area of data mining from the Vellore Institute of Technology, Vellore, in 2017. Has 17 years of teaching experience and has been working as an Associate Professor with the School of Information Technology and Engineering, Vellore Institute of Technology. She organized and attended several workshops and faculty development programs. She actively involves herself in the institute’s growth by contributing to various committees at both academic and administrative levels. She used to guide projects for undergraduate and postgraduate students. She also guides Ph.D. students. She gives technical talks in colleges for the symposium and various sessions. She is an advisory, editorial, and technical committee member in conferences conducted in other educational institutions and in-house. She has published a book titled software project management for college students. She has published research articles in reputed high-impact journals. The Institution of Green Engineers awarded IGEN Women Achiever 2021 in the future computing category. She is interested to explore different places and visit the same to know about the culture and people of various areas. She is interested in learning upcoming things and gets acquainted with the student’s level. Her research interests include information management and data analytics, artificial intelligence (AI), soft computing, medical AI, big data, deep learning, and blockchain software engineering.

...