IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received April 13, 2022, accepted May 20, 2022, date of publication May 23, 2022, date of current version June 1, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3177278

Emerging Technologies for Next Generation Remote Health Care and Assisted Living

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This work was supported by the Academy of Finland through the DigiHealth Project under Grant 326291 and through the 6G Flagship Project under Grant 318927 and Grant 346208.

ABSTRACT Remote health care is currently one of the most promising solutions to ensure a high level of treatment outcome, cost-efficiency and sustainability of the healthcare systems worldwide. Even though research on remote health care can be traced back to the early days of the Internet, the recent COVID-19 has necessitated further improvement in existing health care systems with invigorated research on remote health care technologies. In this article we delve into the state-of-the-art research in latest technologies and technological paradigms that play a vital role in enabling the next generation remote health care and assisted living. First the need of using the latest technological developments in the domain of remote health care is briefly discussed. Then the most important technologies and technological paradigms that are crucial in enabling remote health care and assisted living are emphasised. Henceforth, a detailed survey of existing technologies, potential challenges in those technologies, and possible solutions is conducted. Finally, missing research gaps and important future research directions in each enabling technology are brought forth to motivate further research in remote health care.

INDEX TERMS Telemedicine, 5G/6G, medical IoT, remote care, big data, AI/ML, medical informatics.

I. INTRODUCTION

According to the International Labour Organization (ILO), the aging of population is one of the main problems of this century, since it increases the proportion of old people within the total population. Along with aging population, according to World Health Organization (WHO), the worldwide prevalence of chronic diseases increases fast and new threats, such as Covid-19 pandemic, continue to emerge. Together, these challenges will cause enormous pressure on the efficacy and cost-efficiency of healthcare systems worldwide. The introduction of novel intelligent remote healthcare services is a prominent solution to ensure a high level of treatment outcome, cost-efficiency and sustainability of the healthcare system in this situation. Novel technologies, henceforth, are paving the way towards safe and secure care of patients in remote locations, including homes, remote care units, health care vehicles, and other smart spaces. The technological development in this direction ranges from novel communication infrastructures–enabling connectivity of a variety of health care infrastructural units and objects in remote locations–to smart surfaces, wearable devices, home appliances, and a variety of robots, to name a few. Remote health care, thus, constitutes a whole ecosystem including public, private and personal healthcare facilities, and a conglomeration of emerging technological paradigms intertwined together.

The technological development in the realm of remote health care is multifaceted and is rapidly developing further. A set of diverse technologies have been integrated to monitor

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

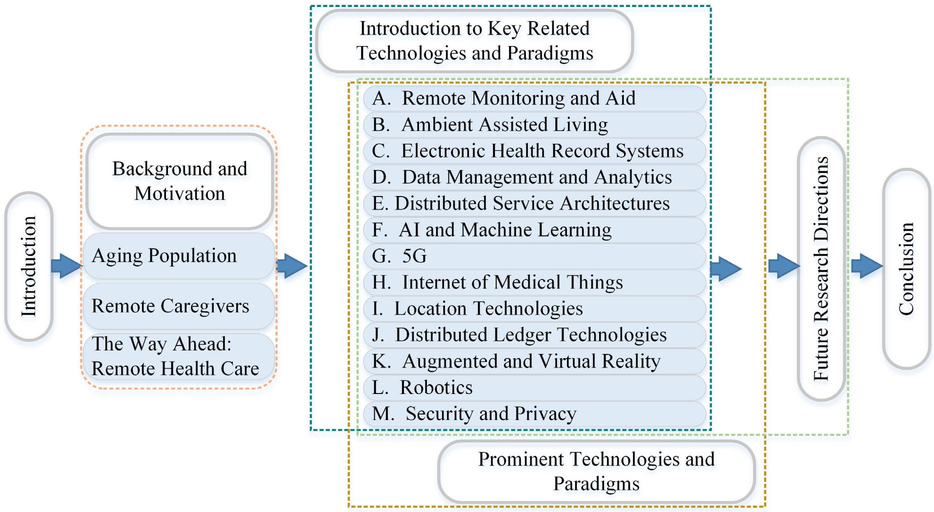

FIGURE 1. Organization of the article with main themes and focus areas of the article.

and provide aid for patients to achieve ambient assisted living (AAL) in remote locations. Novel 5G and forthcoming 6G connectivity will play vital roles in the next generation health care. 5G has already been demonstrated to provide services and connect a diverse set of devices in a secure, reliable, and timely manner as detailed in [1]. Internet of Things (IoT) has also gained a critical role in the health care in general, and remote health care in particular [2], leading to the concept of Internet of Medical Things (IoMT) [3]. Furthermore, distributed ledger technologies [4] have emerged to provide secure transactions, data aggregation and distribution for critical services, with health care being one of its promising application areas [5].

Cloud computing, with its latest developments in the form of edge and fog computing, provides scalable and cost-efficient storage of critical health care information [6]. Wearable technologies for assisted living, such as virtual and augmented reality technologies through smart goggles, provide care-unit like feelings. Social and medical assistance robots help in social and physical activities, thus further minimize relying on relatives and healthcare personnel. Artificial Intelligence (AI) embedding decision-making into latest devices and equipment has enabled critical services to be automated and assist human intelligence with the help of vast amount of data [7] to further improve the well-being and health care of patients [8]. Most of the latest technologies, mentioned above, are also used to maintain electronic health record (EHR) systems in scalable, highly accessible through logical and physical distribution of records, and highly secure manner. In a nutshell, all these technologies have been demonstrated to play a very critical role in enabling the next generation of remote health care services.

The technologies that are deemed necessary for remote health care have also their own inherent limitations related to, e.g., security, reliability, and availability. Furthermore, health care use cases introduce several additional requirements, such as management of patient data in a highly regulated domain of various public and private organizations with various technologies. Therefore, assessing the technological development towards independent AAL through remote monitoring and aid is not only essential from the technological developments perspectives, but also from the readiness of societies to handle future needs. Thus, careful study of the state-of-the-art in each of the enabling technologies from the perspectives of remote health care is extremely important. It is the need of the day to investigate the limitations in these technological developments, existing solutions for such limitations, and the remaining research gaps to motivate further research in this direction. Therefore, in this article we dig deep into the latest state-of-the-art in each of the enabling technologies of remote health care.

In this article, first we motivate the need of remote elderly care, which is one of the most important application areas for remote health care, based on the growing elderly population, their preference to stay independently and at homes, and the shortage of health care professionals along-with high health care costs. Then we overview the most important technologies and thoroughly discuss the state-of-the-art in each technology followed by future research direction. This article is organized as follows: In Section II, background and motivation are discussed using examples of increasing aging population and the need of remote healthcare for the elderly. Related work is discussed in Section III. The most important technologies are briefly outlined in Section IV. Then the prominent technologies and technological paradigms are discussed in Section V, which makes the main part of the article. Section VI provides important future research directions, and the article is concluded in Section VII. For smooth readability, the outline of the article with main themes and focus areas are depicted in Fig. 1, and the most used acronyms

TABLE 1. List of most common abbreviations.

Acronym	Full term(s)
5G	Fifth Generation
AAL	Ambient Assisted Living
ADL	Activity of Daily Living
AI	Artificial Intelligence
AR	Augmented Reality
BAN	Body Area Network
BLE	Bluetooth Low Energy
CPS	Cyber-Physical System
CSI	Channel State Information
D2D	Device to Device
DLT	Distributed Ledger Technology
DPI	Deep Packet Inspection
DR	Dead Reckoning
DT	Decision Trees
DRL	Deep Reinforcement Learning
EHR	Electronic Health Record
EC	Edge Computing
ELM	Extreme Learning Machine
eMMB	enhanced Mobile Broadband
FC	Fog Computing
FTM	Fine Timing Measurement
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IaaS	Infrastructure as a Service
ICT	Information and Communication Technologies
IDS	Intrusion Detection System
IoT	Internet of Things
IoMT	Internet of Medical things
LWPAN	Low Power WAN
MEC	Multi-access Edge Computing
mIoT	massive IoT
mMTC	massive Machine Type Communication
NFV	Network Function Virtualization
NLP	Natural Language Processing
PaaS	Platform as a Services
QoL	Quality of Life
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RFID	Radio Frequency Identity
RSS	Received Signal Strength
RTT	Round Trip Time
uRLL	ultra-Reliable Low Latency
UWB	Ultra Wideband
VNF	Virtual Network Function
VR	Virtual Reality
WASN	Wireless Acoustic Sensor Networks
WBAN	Wireless Body Area Networks
WSN	Wireless Sensor Networks

are presented in full form in Table 1. The terms ''health care'' refer to individual technologies and technological paradigms, whereas the word ''healthcare'' refers to the public healthcare systems in this article. Due to the nature of the article, we use ''health care'' mostly in this article.

II. BACKGROUND AND MOTIVATION

A. AGING POPULATION

According to the United Nations world population prospects 2019, the global population is expected to reach 8.5 billion by 2030, 9.7 billion by 2050 and 10.9 billion by 2100. The number of people aged 65 years or more globally is projected to more than double from 2000 to 2050, while the number of children under five is projected to remain relatively unchanged, as depicted in Fig. 2. Globally, in 2019 Europe and North America have had the most aged population, with

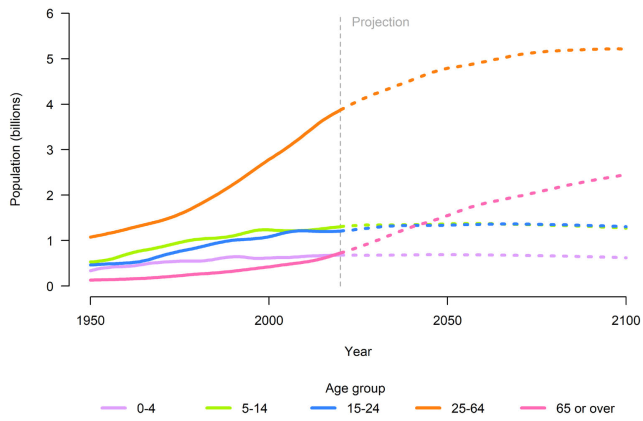

FIGURE 2. Persons aged 65+ years make up the fastest-growing age group [9].

18 percent aged 65 years. The trend for age increase will continue also in the future. The number of people aged 80 years is growing even at a higher pace. Specifically, in 1990 there were 54 million people aged 80 years globally, and this number has number nearly tripled (143 million) by 2019 [9].

Advanced medical systems and technologies, improved public health and personal hygiene has been the main contributor to the increase of life expectancy in recent decades. However, the growing average age of the population is disturbing the socioeconomic structure of many countries through increasing the burden (i.e., the manpower and costs) on health care on the one hand, and deteriorates the existing standards of well-being of elderly people on the other hand [10]. Specifically, aging leads to various chronic diseases and conditions such as heart disease, stroke, cancer, diabetes and dementia [11]. Due to these diseases, the elderly require frequent and immediate medical intervention, and assistance in their daily activities, which may otherwise result into fatal consequences [12].

The significance of remote health care has emerged to the forefront during the COVID-19 pandemic in which elderly people, especially those who suffer from chronic diseases, are confined to their homes. This has raised huge challenges for the existing healthcare systems and impaired their capacity to deliver services not only those who are COVID-infected, but also the ones suffering from other conditions [13]. Moreover, public health care in almost all countries have faced huge burden causing long waiting durations and delays on medical visits, thus ultimately affecting life of the elderly [14]. Hence, the need and importance of remote health care systems and services have become practically pivotal to the very functioning of modern societies.

Notably, some conditions develop and progress with aging. A good illustration is dementia, which is one of the most common health problem that requires proper assistance. The typical symptoms of dementia in seniors include memory loss and problem-solving capabilities, and difficulties in communicating and performing routine tasks including activities of daily living. Dementia has many causes, but Alzheimer is among the most common reasons of dementia. Alzheimer is a type of brain disease that is also degenerative meaning that it becomes worse with time. A person with Alzheimer diseases experiences multiple symptoms that change over a period of years.

The disease progresses through three stages: mild, moderate and severe. In the mild/early stage dementia, a person can perform most activities independently, but requires little assistance for some actions. As the dementia progresses to moderate stage, which is the longest stage of dementia, most people face difficulties communicating and performing Activity of Daily Living's (ADL's), and may occasionally get frustrated or even demonstrate aggressive behaviour. In the severe stage of dementia, people become fully dependent on someone because they need assistance around-the-clock for all their daily activities [15]. Since the need of assistance increases due to deterioration in cognition, physical functioning and behavior, the role of caregiver and novel technological solutions arise and increase with time. Below we discuss the role of different actors in the process of providing assistance to the elderly.

B. SITUATION OF REMOTE CAREGIVERS

Caregivers can be, generally, categorized into formal and informal. Formal caregivers are usually paid professionals or care services providers from institutions and include nurses, personal support workers, rehabilitation specialists, and physicians, etc. [16], [17]. Informal caregivers, are, e.g., family members and relatives who take care of a loved one requiring assistance. Due to the rapid increase in aging population worldwide, the demand for formal and informal caregivers rapidly increases every day.

The expenses related to both types of care-giving are rising. In formal care-giving, big economic burden is associated with the care process. For example, the worldwide economic burden of dementia only (formal and informal care combined) is estimated to be over a trillion US dollars [18]. At the same time, the informal caregivers also spend substantial time, resources and time to support elderly in everyday tasks. On the positive side, living at home and getting help from family and friends enables cost saving to the healthcare system and may prevent transferring of an elderly to a care home [18]. On the negative side, only few informal caregivers possess proper training and can provide care services in professional manner.

Technological solutions can close the necessary gap of resources to enable professional caregivers providing the necessary care remotely. Technology is already playing a big role in supporting caregivers and most care givers believe that technology can help them to make care giving more efficient, effective, safer and less stressful [19]. Technological solutions, i.e., telehealth and remote activity monitoring, for instance, do not only help monitoring and taking care of patients and loved ones, but also enable efficient and smooth communication with health care professionals and other care providers [19], [20]. Below, we discuss in brief how the emergence of remote health care helps elderly in particular and opens a way ahead for remote health care services in general.

C. THE WAY AHEAD: REMOTE HEALTH CARE

Remote health care bases on the use of modern and state-of-the-art information and communication technologies (ICT) to enable caregivers (formal and informal) and healthcare professionals to remotely monitor and assist elderly in their homes thus keeping them safe and supporting their independent life [21] from anywhere and at anytime. Remote health care systems/devices often incorporate sensors worn by the user or installed at home that can send timely alerts to a monitoring center if something goes wrong and thus helping to prevent a problem before it occurs. Simultaneously, they can track and report the real-time location and enable a patient to get a consultation on the medical condition without leaving home. The main benefits of using the remote health cares systems include improving the quality of life (QoL) of the elderly, caregivers and medical professionals, reduction of stress and burden, and reduction of costs of the care giving and receiving process.

Notably, the progress in remote health care allows elderly to remain in their home or in their familiar environment and live comfortably and independently rather than moving to expensive nursing home or hospitals. At the same time, they reduce travelling cost as patients can get early treatment and diagnostics from home. Moreover, hospitals and healthcare system in general benefit from telemedicine by improving the resource utilization and bed occupancy as patients can be treated anywhere and anytime. The real-time vital sign reading obtained and transmitted from wearable devices can also help the remote medical staff to found or prevented the early illnesses. Notably, telemedicine provides health care equality as people from around the world can get medical services as soon as they are connected to the Internet. Moreover, local or international physicians can meet, learn and exchange knowledge from other professionals from all over the world [22].

However, there are a number of challenges associated with the adoption of remote health care systems. For example, many researchers have focused on age-related factors while designing applications and systems for older adults. As people age, physical and sensory limitations such as hearing, vision, motor and cognition impair their ability to understand and master the new technologies [23]. Hence, there challenges of adoption and adaptation come to the forefront. Furthermore, patient's data confidentiality and privacy are critical aspects of remote health care technologies. Proper infrastructure for both patients and care givers with high resolution video cameras, stable broadband connectivity, reliable wearable/sensing devices, intelligence in devices to act in autonomous and context-aware fashion, and with security spanning through the whole ecosystem still demand further research efforts. In the following section we proceed by over-viewing the current state of the field and pinpointing the existing survey and review articles dealing with the different aspects of the remote health care.

III. RELATED WORK

Remote home care has become increasingly important recently not only due to the technological developments, but mainly due to the difficulties in human support and limitations in resources in centralized facilities to cope with the growing number of the elderly. Therefore, huge research efforts are dedicated towards providing remote health care at homes, and thus, existing and new technological developments are directed in this direction. In this section, we provide an overview of the existing survey articles that discuss emerging technologies for remote home care.

A comprehensive study on remote patient monitoring is conducted in [24]. Communication technologies have enabled the connectivity whereas sensor technologies have enabled monitoring the vital signs of patients, thus, enabling active patient monitoring. Authors in [24] provide an overview of survey articles between 2012 and 2016 on the theme of remote patient monitoring. Existing work of the time is categorized into i) Cardiovascular system and respiratory system-related diseases, ii) Fall detection and mobility-related diseases monitoring systems, iii) Brain, Neurological Disorders and Mental Health, iv) Diabetes, and v) general systems that can be used, for example, in the monitoring of children, pre-hospital assistance.

A recent survey on the applications and technologies of IoT in health care is presented in [25]. IoT-based health care networks are classified, standard IoT health care protocols are analysed, various health care applications and services are discussed, and insights into the security and privacy of IoT used in health care are provided. Furthermore, the work proposes a model for IoT health care security and discusses the market opportunities in the sector. The proposed model suggests improved device-level and OS-level security, as well as using blockchain for improved data integrity.

Currently, the most important use-case of remote health care is the care eco-system for the elderly. The main reason behind the use case is not only the growing elderly population due to improved quality of life, but also due to the technological development that has made it possible to provide nearly the same type of care as in well-equipped public facilities. As a result, there are huge research efforts in this direction. A concept of the smart house for old persons and individuals with physical disabilities is presented in [26]. The authors provide an extensive survey of the main building blocks of smart houses, focusing particularly on the health monitoring systems. The authors classify the structure of smart houses into four groups on the basis of: i) movement disabilities, ii) age (older persons), iii) vision impairment, iv) hearing impairment, and v) cognitive impairment. All of these groups have their own requirements, and thus have distinctive technologies and their uses. The article highlights that the development strategy of intelligent technologies installed at home has changed from the design of separate devices towards integrated environments where devices communicate and cooperate. A shift from hardware to software-based systems, human-friendly, miniature and modular design of components of smart houses is considered as the way forward.

The role of technological developments and their impact on the patients of dementia is surveyed in [30]. The main dimensions of the technology developments are identified as i) diagnosis, assessment and monitoring, ii) maintenance of functioning, iii) leisure and activity, and iv) caregiving and management. The ethical considerations of assistive technologies and telecare for people with, so-called, intellectual disabilities are discussed in [33]. The authors conclude that the introduction of assistive technologies and telecare involves the transfer of control from staff to technology. The most important lessons include ensuring the safety of the technologies, as well as increased sharing of experiences to further improve the quality of services and related ethical standards. Telemonitoring the daily activities of the elderly in order to improve the quality of their lives and health care has been reviewed in [27]. The focus, however, is not on the latest technological developments.

A systematic review on predicting infections using computational intelligence is presented in [31]. The article concludes that machine learning has been used in most of the works, and that computational intelligence is well-documented in the medical literature. A survey on using mobile phones for sensing, self-reporting and sharing of health information is published in [34]. The main focus of the article is pervasive health care, i.e, providing health care anywhere and at anytime. The current state-of-the-art in pervasive health care is divided into personalized monitoring through i) mobile phone sensing using in-built or external sensors, ii) self-reporting of health information captured manually, and iii) social sharing of health information in an individual's own community.

IoT for monitoring the elderly remotely has been discussed in [29]. The article studies IoT-enabled systems for monitoring the elderly while focusing on the requirements of the elderly. The study reviews the existing work in the domains of remote health monitoring, nutrition monitoring, safety monitoring, localization and navigation, and the applications of IoT in enabling social networks of the elderly. The study published in the year 2017 highlighted that there is a need for personalized monitoring, techniques for emergency monitoring, and extensive and long-term monitoring. A systematic review on smart homes and home monitoring health technologies is presented in [28]. The main focus of the article is on the readiness level of technologies for smart homes to support adults, which is low according to the study. The study has been published in 2016 and thus does not cover the latest developments in remote home care, such as 5G, that is one of the infrastructural enabler of remote health care systems.

Even though there are studies from different dimensions focusing on the technological developments for remote care

TABLE 2. Existing survey and literature review articles with main focus highlighted and compared to our article.

Publication Year	Reference	Focus	Limitations
2004	[26]	Smart house for he elderly and persons with physically disabilities	The article is old in terms of recent technological developments
2013	[27]	Monitoring activities of elderly and the effects of telecare on their lives	The focus is not on the technological developments
2016	[28]	A survey on the use of mobile phones for pervasive health care	Limited to the use of a handheld device
2017	[29]	A review on the state-of-the-art of IoT-enabled systems for monitoring the elderly	The main focus is on IoT and localization technologies
2019	[24]	Survey on patient monitoring technologies, mainly vital signs of patients	Does not cover the rest of dimensions of remote health care
2019	[30]	A study on technological developments for the patients of dementia	The main focus is limited to the needs of dementia patient, not covering the latest technologies
2019	[25]	A survey on the applications and technologies of IoT in healthcare	Not focused on remote health care technologies.
2020	[31]	Systematic review of computational intelligence in prediction of infections	Focused is generally on spread of infections
2021	[32]	A survey on 5G based healthcare systems, mainly based on IoT	The main focus is on 5G and its capabilities to serve IoT, not covering other technologies in depth
Our article	Provides a comprehensive state-of-the-art in enabling technologies and technological paradigms of remote health care.		

from different dimensions, there is a lack of studies that provide an update on the technological developments from the holistic point of view. Remote health care has become an ecosystem with the help of the latest technological developments that integrate various diverse technologies to provide a range of services from the medical attendance that would otherwise be only possible in modern hospitals. Therefore, in this article, we carry out a thorough study, first on finding the most important technologies that will play a vital in the future of remote health care, and then, we study the development in those technologies for the said purpose. A thorough research is carried out on the latest and emerging technological developments for the next generation remote home care. Latest technologies such as 5G, blockchain and distributed ledger technologies (DLTs), AAL, the IoMT, augmented and virtual reality, and state-of-the-art localization technologies, to name a few. Therefore, in a first of its kind, this article attempts to provide a comprehensive survey of the state-of-the-art technologies that are either used, or will be used in the remote health care. For comparison to existing survey articles, we have summarized the available surveys with their limitations in the view of this work in Table 2. To the best of our knowledge, none of the existing articles have studied the technological developments in the domain of remote health care as we have deliberated in this article.

IV. A BRIEF OVERVIEW OF KEY RELATED TECHNOLOGIES AND PARADIGMS

In this section, we provide a brief overview of the most important technologies and technological paradigms which play a vital role in enabling remote health care. These technologies and technologies paradigms are highlighted and summarized in Table 3. In the following subsections, we briefly elaborate the need of these important technologies in remote healthcare.

TABLE 3. A brief summary of key related technologies and technological paradigms.

Key Technologies and Paradigms	Brief Description
Remote monitoring and aid	It allows remote patient monitoring and provisioning of medical services remotely.
Ambient assisted living	It technologically enables care receivers to live independently in remote locations.
Electronic health record systems	These systems maintain all health related data and are capable to share it using latest ICT.
Data management and analytics	Huge data is generated in modern healthcare and thus taking right decisions at right time is helped by efficient data management and analytics.
Distributed service architectures	It represents new service architectures that enables processing and storage of healthcare information near the users to provide timely health care.
AI and machine learning	Analysis of huge amounts of data generated by big number of devices, such as MIoT, is done by the latest technologies and tools in AI and machine learning.
5G	5G provides the underlying connectivity infrastructure for the remote healthcare technologies and services.
Internet of medical things	It makes the junction of IoT and the medical discipline with profound benefits to healthcare ranging from the development of specialized healthcare-specific IoT devices and connectivity infrastructure to enabling the novel services and practices.
Location technologies	It allows accurate positioning of patients, remote care units, vehicles and personnel to enable healthcare services such as accurate monitoring and assistance.
Distributed ledger technologies	To securely share and exchange data, and keep track of its use.
Augmented and virtual reality	To provide visual remote assistance to care receivers and a mode of monitoring for caregivers.
Robotics	Robotics have huge number of applications in the healthcare ranging from remote assistance and help to remote surgeries.
Security and Privacy	The sensitivity of user information necessitates strong security and privacy techniques being in place.

A. REMOTE MONITORING AND AID

Remote patient monitoring provides useful alternatives to monitor and track the user's healthcare conditions outside of traditional health care settings, such as hospitals and care units. It also facilitates early detection of medical conditions requiring attention from health care professionals. The current remote monitoring solutions are typically based on wearable sensors, such as a wristband, locally connected to a mobile phone app via Bluetooth or other short-range wireless connection, and the mobile phone is further connected to cloud via a cellular or WiFi connection. In addition to delivering sensor data to health care professionals, also other services can be included. A patient can, e.g., use the app to have a video conference with her/his doctor to discuss the treatment process [35].

B. AMBIENT ASSISTED LIVING

Ambient assisted living (AAL) has the potential to enable people to stay active longer, remain socially connected, perform their ADLs and live independently at home. The main aim is to ubiquitously enable the required user assisted services in a secure manner in both indoor and outdoor environments. It refers to the use of ICT by using smart homes, assistive robots, and mobile and wearable sensors [36]. Various studies, such as presented in [37], show that the role of smart phones is increasing and useful applications for patient training, sickness self-administration, and remote supervising in health care systems are showing good results. Hence, the domain of AAL is rapidly evolving and the corresponding developments in the enabling technologies, devices/sensors, data analytics mechanisms, and novel interaction modalities, among others, are becoming increasingly important [38].

C. ELECTRONIC HEALTH RECORD SYSTEMS

Electronic Health Record (EHR) systems are the backoffice systems for other digital services like remote care. Health care information and communication technology has become an everyday companion for physicians and nurses who are utilizing the information contained in their institutional EHR while making everyday decisions of patient care. In developed countries like Finland, the current availability of electronic health record systems is 100 % both in public and private care [39]. Telemedicine and eHealth solutions connected to an EHR are an inherent part of digital transformation and they extend from professional consultation services to mHealth and self care solutions targeted to citizens [40], [41].

D. DATA MANAGEMENT AND ANALYTICS

Health care has become one of the major emerging users of big data analytics, as lots of data is coming from various sources, such as wearable devices, IoT devices, experimentation on diseases, hospital's record, and from patient EHR systems that consists of patient data, test results, and radiology images. This data is in the form of unstructured and structured data. Big data can be used to benefit a wide range of health care organizations, from individual physicians, a local community hospital, or chain large hospital networks [7]. The main objective of big data analytics in health care is to improve patient-centered care, detect disease and outbreaks early, provide new insights into disease mechanisms, monitor the quality of medical and health care institutions, and develop better treatment approaches, to name a few benefits. The big data management in health care industry is carried out through various state-of-the-art tools and techniques in each phase including data acquisition, storage of data, managing the data, analysis on data and data visualization.

E. DISTRIBUTED SERVICE ARCHITECTURES

For the past decade, cloud computing has been the primary solution to provide platform-independent services through the Internet. It offers a multitude of benefits such as Infrastructure as a Service (IaaS) providing offering computing, storage, and networking resources on demand for service providers, Platform as a Service (PaaS) to deliver online hardware and software tools for service developers, and Software as a Service (SaaS) to provide online applications for end-users [42], [43]. In today's cloud computing, microservice architectures [44], [45] have replaced the traditional monolithic service architectures as a foundation of cloud computing systems. Microservice architectures decompose monolithic applications into smaller independent services or processes that can be distributed in the cloud computing infrastructure, with the aim to ensure the optimized performance of applications while maintaining high level of system-wide flexibility, scalability and maintainability [45], [46]. Despite the increased service architecture decentralization, traditional cloud computing, based on centralized data-centers, fail to meet the latency and reliability requirements of real-time and mission-critical applications present in many healthcare use cases. To overcome this problem, the concepts of edge and fog computing have been developed to bring parts of the micro-service architecture from data centers to edge servers, closer to the end user and IoT devices [47].

F. AI AND MACHINE LEARNING

Many studies have highlighted the efficacy and potential of Artificial Intelligence (AI) in the field of health care. Various popular AI techniques such as machine learning, deep learning, natural language processing (NLP), neural nerworks are used to develop health care applications [8]. There has been an active discussion if AI will replace the human physicians and many believe that it would not be possible in the foreseeable future, but AI can definitely assist physicians to make better clinical decisions or even replace human judgement in certain functional areas of health care [48]. The most influential area of AI-enabled health care delivery are health care administration, clinical decision support, patient monitoring, and health care interventions [8].

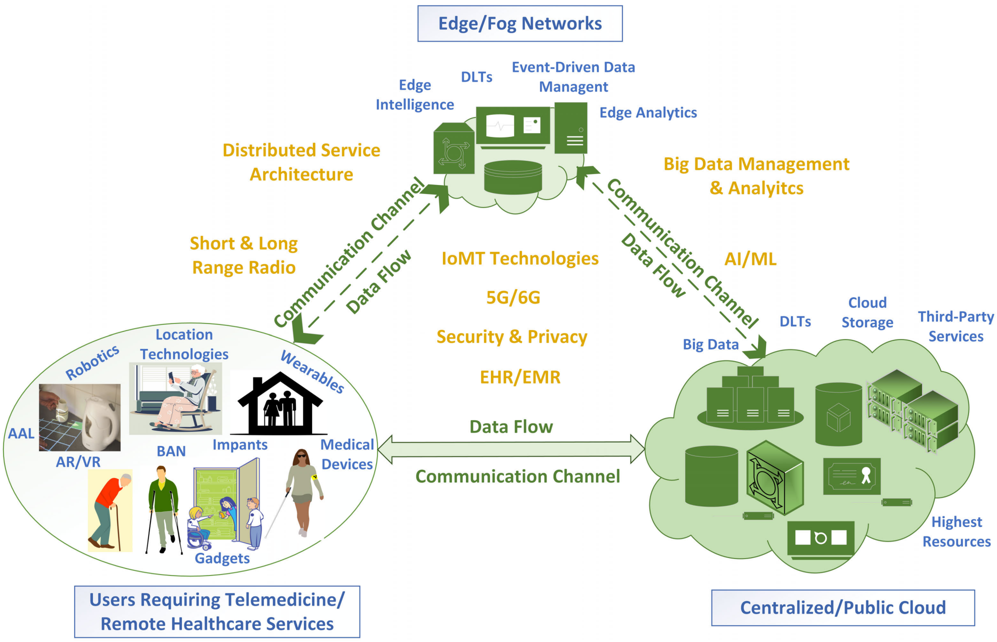

FIGURE 3. Overview of emerging technologies for next generation remote health care.

G. 5G

5G provides the basic underlying communication infrastructure for all types of digital systems that need connectivity. 5G has the ability to provide high data rates with extreme low latency, high reliability and security. Such capabilities can overcome the limitations that existed in the previous generations of communication networks hindering a diverse set of critical services that require highly availability and reliability, for instance telemedicine and remote surgery. Particular to remote healthcare, 5G brings a major shift towards patient-centric provision of services that can be tailored to specific use-cases and scenarios of remote healthcare. For example, medical services can be provided a dedicated slice that has all the configurations set to ensure protection of highly sensitive information, provide high reliability through dedicated links and localized processing through edge computing. Furthermore, 5G uses a variety of latest technologies ranging from machine learning to softwarizing network functions to embed intelligence and flexibility in communication systems. Thus, 5G has a higher potential for enabling remote health care [49], [50].

H. INTERNET OF MEDICAL THINGS

The application of the Internet of Things(IoT) concept to medicine, health care and well-being, which has even got an own term-the IoMT [3], promises a new technological revolution. By enabling the connectivity between the versatile machine-devices (such as static and wearable sensors, actuators, cyber-physical systems, and cloud/edge servers) as well as between them and humans, the exciting novel applications and health care paradigms can be enabled. Notably, as we show in what follows, the landscape of the IoT and IoMT connectivity technologies is extremely diverse. On the positive side, this allows them to address a number of needs and use cases relevant for remote healthcare and assisted living already today. However, on the negative side, the lack of common ontology and interfaces results in poor interoperability of the different solutions. This is worth noting, that in what follows speaking about the IoT/IoMT to provide a more comprehensive picture we also consider the machine-networks not connected to/though the Internet (thus steering towards the definition of IoT given, e.g., by ITU-T and IoT-A as discussed in [51]).

I. LOCATION TECHNOLOGIES

Positioning technologies can be used in remote home care to assist elderly people to find their routes inside buildings and also locate things needed in everyday life. Tracking of movement patterns and postures can help in detecting illness and emergency situations [52]. Satellite-based solutions mainly help in outdoor activities and there are also numerous technologies for indoor localization. Recent studies have both developed accurate solutions using optical, radio, and magnetic signals and also looked how to efficiently integrate techniques together. Combination of global navigation satellite systems (GNSS) and 5G technology [53] can provide localization that works seamlessly in indoor and outdoor environments.

J. DISTRIBUTED LEDGER TECHNOLOGIES

Distributed ledger technology has attracted stakeholders from a variety of industries, including health care. Blockchain's key properties, such as decentralization, transparency, and immutability, have the potential to address pressing issues in current health care, such as patient data centralization, which can lead to a single point of failure, and data breaches, which can jeopardize system reliability and availability [54]. Distributed ledger technology has a multitude of features that can be utilized in the telemedicine industry such as decentralized storage for enhanced security and authentication, data integrity and immutability, and secure data sharing by providing provenance and auditing [5]. The use of blockchain technology in the telehealth care industry will enhance the transparency and communications between patients and health care providers [55]. For example, Gem, a startup, launched the Gem Health Network based on the Ethereum blockchain technology [56], this shared network infrastructure combines businesses, individuals, and health experts, which at the same time improve patient-centred care while addressing operational efficiency issues.

K. AUGMENTED AND VIRTUAL REALITY

VR and AR are emerging technologies and various applications has been developed from entertainment to health care. VR and AR have great potential to improve and maintain functionality, autonomy, well-being, as well as prevention and treatment of the older adults. Though AR and VR have huge potential to promote and improve the well-being of elderly people, studies related to this group have not been conducted actively [23]. VR allows older adults to be fully immersed in a virtual environment that seems like the real one. AR layered virtual information onto the real world provides the virtual experience of the real world. VR and AR provide immersive experiences of some places that the older adults cannot visit due to health problems. Hence, VR and AR applications are widely used to make the life of older adults better, convenient and enhance their well-being.

L. ROBOTICS

Robotic technologies have been used in a variety of settings in healthcare facilities. They have been considered as assistive devices that could help bridge the growing gap between healthcare demand and supply. They can help a patient to stay healthy and safe in the comfort of their own homes. Healthcare robots are categorised as either rehabilitation robots or social robots [57], and can perform a wide range of tasks. Rehabilitation robots are physically assistive devices that help people perform different activities or make them easier. On the other hand, social robots have an easy likeable interface and act as a companion. Healthcare robots are intended to help people live independently by assisting with mobility, home activities, and health monitoring. Many companies have begun developing and testing healthcare robots for the elderly and children. Several studies have demonstrated that social robots can help elderly persons reduce anxiety and depression while also improving their quality of life. They also have the potential to improve engagement, social interaction and reduce loneliness [58]. The RAMCIP (Robotic Assistant for Mild Cognitive Impairment Patients) [59] is an example of a service robot that was built as part of the EU 2020 Horizon Project.

M. SECURITY AND PRIVACY

Security and privacy are highly important from many aspects in remote healthcare systems. The safety and well-being of the care receiver and caregiver, as well as the safety and routine operations of the working environment are all dependent on the security of the systems. Moreover, there are many dimensions in security and privacy, such as security of the operating systems in the environment, the communication infrastructure that connects the components in the operating environment, and security of the wearable devices, IoT and sensor nodes. Hence, security and privacy in remote home care is pretty complex and, thus, challenging that require further study.

V. PROMINENT TECHNOLOGIES AND PARADIGMS

The main aim of remote health care systems is to enable remote monitoring, provide remote aid whenever and wherever necessary, and thus, ensure an ambient assisted living. The technologies that enable such assisted living through novel monitoring and aid-giving technologies are well researched, ranging from basic connectivity infrastructures such as 5G, to small wearable devices or implants such as AR/VR googles and MIoT sensors, to assistive robots. This section discusses in detail these important technologies and technological paradigms, starting from remote monitoring and aid below.

A. REMOTE MONITORING AND AID

The main purpose of enabling remote patient monitoring (RPM) services is to go beyond conventional and standardized modes of in-hospital patient health monitoring by allowing the remote sensing, gathering, analysis and assessment of patient's healthcare information [60], [61]. Remote patient monitoring and treatment are considered as integral part of modern telehealth solutions. It improves the overall quality of healthcare systems by providing a connected healthcare ecosystem where the continuous remote monitoring of the patients and elderly can be performed through different invasive and non-invasive approaches can be performed. Furthermore, the real-time data transmission to the medical-experts is ensured so that needed operations or actions will be carried out accordingly [62]. Hence, these system saves time, cost, resources and increase the efficiency of healthcare systems [63].

The modern remote patient monitoring systems take immense benefits from the recent technological advancements. It utilizes wide range of enabling technologies as well as standardized health care practices to provide needed monitoring services for both the cases, i.e., when the person is indoor or doing any outdoor activity. The advanced remote monitoring system will integrate various IoMT technologies such as medical sensors/devices, WBAN, smartBAN, short and long-range technologies (RFID, BLE, ZigBee, WiFi), mobile sensing and communication technologies and cloud technologies for data processing, storage and analysis. Wearables (such as smart watch, fitness band, smart ring) can be with the patient all the day and monitor the vital signs. The European Telecommunications Standards Institute (ETSI) has already produced smartBAN, showing the maturity of ICT in remote patient monitoring [64].

Remote and continuous monitoring services are needed for analyzing different vital signs and related health parameters for the diverse categories of users, e.g., elderly, disabled persons, and the patients with chronic or contiguous diseases. Following are some of the different target groups which may require various set of remote monitoring services [65], [66].

- **Persons with chronic diseases:** Chronic diseases are considered as a major cause of the deaths and disabilities around the world. Recently, there has been seen a rising trend in chronic diseases in the developing countries mainly due to the ageing of population [67]. Some of the most common/frequent chronic diseases may include asthma, alzheimer/dementias, arthritis, cancer, heart diseases, hypertension, lung diseases, and strokes among others. Furthermore, several patients may also possess the state of comorbidity, i.e., simultaneous presence of two or more diseases, which even worsen the impact of chronic diseases. Therefore, it is highly important to enable continuous remote monitoring services to keep track of these changes.
- **Persons with contiguous diseases:** Contiguous diseases such as COVID-19, flu, influenza, tuberculosis etc. can spread or transmitted easily from one infected person to the number of non-infected people. For example, the recent Coronavirus is spreading very rapidly around the globe mainly through the physical contact of the infected person. This has also caused huge burden onto the hospital infrastructure as they do not have the enough capacity to deal with all the infected patients. One approach to tackle this challenge is to enable remote monitoring of the patients with mild symptoms from their home only and those requiring intensive or urgent care can be treated in the hospital.
- **Elderly persons diseases:** Since the elderly population is increasing, the number of associated diseases are rising as well [68]. For example, elderly patients may have multiple diseases i.e chronic diseases, brain related diseases, memory loss etc. It also has been seen that the most of senior citizens prefer to live alone or away from the urban areas. Therefore, it is highly important to provide cost-efficient remote monitoring services for the elderly at their own home or to the elderly care).
- **Post-surgery:** Postoperative complications are seen as the prime reason of most of the deaths in surgical patients [69]. One of the major cause is due to the lack of surveillance or health monitoring mechanism for the patients after discharging from the hospital. Though after the surgery the follow-up checkups are usually planned by the doctor to check the postoperative health conditions, but it may not be a good strategy for high-risk patients. Therefore, remote monitoring and assessment of postoperative patients are vital to keep track of patients conditions after the surgeries, e.g., cardiac surgery, brain surgery and liver transplant etc.
- **Disabled persons:** Disable person can perform the limited physical activities and hence getting the medical services on their own might be difficult at times. Remote monitoring services are needed according to the specific requirements of different persons with disabilities.

Several remote patient monitoring systems are already proposed in the state-of-the-art. For example, the work in [70] developed a wearable and ML integrated surveillance platform that can provide the mobile enabled remote monitoring of a patient having knee arthroplasty. In [71], a graphical user interface based smart home monitoring system for patient's using the ML techniques (supervised learning) which can predict the chronic diseases such as type 2 diabetes and hypertension. Another research work in [72] have designed and developed a real-time fog-enabled remote monitoring system for the diabetic patients which based on their physiological signals, can monitor and analyze different vital signs of the patients, e.g., blood glucose level.

Recently, with the increasing demands of the remote medical services and treatment, the role of telemedicine in the current and the future health care ecosystem has become critical. For example, the on-going COVID-19 pandemic situations has clearly shown the need, importance and urgency of the advanced telemedicine and virtual care systems [73]. These smart telemedicine systems can ensure the continuation of basic healthcare facilities/treatment remotely to the wider audience, i.e., patients with routine illness, elderly people, disabled persons, COVID-19 infected persons (with mild symptoms) etc. In this way, the overall burden on the hospital emergency and other units can be reduced and that can allow the hospital administration to put more focus, efforts and resources for the treatment of higher-risk patients [74].

Traditionally, the telemedicine systems were designed to enable the remote medical services in the rural areas where the medical facilities are usually very limited (i.e., in terms of lesser medical units, doctors and other expert staffs) [75], [76]. However, due to increase in aging of the population together with many other factors (e.g., rise in new diseases such as COVID-19), the applicability of these virtual care systems can be seen beyond the rural areas (i.e, even in the large cities/suburbs). For example, elderly patients having some chronic diseases or disabled persons usually require more medical checkups and frequent visits to the hospital, which might not be realistic in-practice due to several reasons such as, higher dependencies and costs, increased chances of getting infected from other diseases [77]. Hence, telemedicine systems can provide huge added value to the current healthcare systems by enabling secure, cost-efficient remote health care services.

The key objectives of the telemedicine systems include the efficient use of medical resources, improving the overall quality of healthcare services, reducing the costs and congestion of hospital, and expansion of the service accessibility. With telemedicine systems, patients can acquire customized remote healthcare services using the telecommunication infrastructure and relevant enabling technologies, tools and softwares, such as video conferencing, smart phones and cloud computing [78], [79]. Examples of such enabling technologies include, mobile and remote applications, robotics, enhanced sensing and communication technologies, advent of fast speed 5G and beyond systems, AI and data analytics, and blockchain among others. In addition technologies such as VR/AR based communication technologies are revolutionizing the telemedicine services by to simulating the patient's information and a graphical environment together with video conferencing to enable better and reliable communication with a doctor. Hence, telemedicine has evolved over the years and can be of various shapes, e.g., online patient consultation, telehealth nursing, telehealth rehabilitation, telecardiology, teleneurology, telediabetes, remote control, and teleemergency services among others [78], [80].

Telemedicine can roughly categorized into three forms as discussed following [81]. The first is 'store and forward' which deals with the collection/fetching of the healthcare (e.g. medical images) data and sending it to the doctor or medical expert. 'Remote patient monitoring' is the second category where the monitoring is performed through the medical sensors/devices, wearables and video surveillance (using digital cameras). These both types are also known as Asynchronous patient care because it doesn't necessarily require for both the patient and service provider to be online same time for the treatment, i.e., medical reports, sensed/monitored data can be sent to the cloud or their servers which can be analyzed by the provider [82]. The final one is 'real-time interactive services' which is more like Synchronous patient care that brings services such as the online/real-time video-based patient's consultation with the doctors and medical specialists.

The research community has already predicted that the telemedicine systems are going to play a vital role of the telemedicine in the healthcare system ecosystem of the 21st century. However, the actual progress into terms of fully adoption of these systems on a larger scale is relatively quite slow due to several open challenges [83]. For example, the research work in [84], [85] elaborated various barriers and challenges in this context. Infrastructural and access barrier deals with the challenges related to the accessibility of the services to the far-away rural areas where the infrastructure is unstable or less-reliable. In addition, the smooth delivery and availability of the healthcare services to the disabled persons and to the low-income consumers (due to higher costs) would be challenging as well.

From the individual patient's perspective, ensuring the privacy and confidentially of sensitive information considered as one of the critical challenge in the global acceptance of the telemedicine systems [86]. Another important obstacles would be agreeing on the various regulatory and legal matters associated with the telemedicine systems, e.g., clear and standardized set of rules on cost reimbursement/insurance terms throughout the whole process [87]. Moreover, appropriate solutions are required to the cultural barriers and to the lack of the operational capabilities and technology awareness for the worldwide adoption of these systems.

B. AMBIENT ASSISTED LIVING

With the continuous increase in the ageing population, innovative and cost-efficient technological solutions are required that can allow the elderly to get health care assistance from their home/residence [36]. AAL environments are seen as highly important in the context of enabling health care services and providing assistance to the needed persons in the most natural way [88]. A number of sensors, devices/equipment, cameras, microphones and others needed tools and technologies in an AAL environment can collaborate to deliver context-aware health care services to the required users [89]. Hence, AAL environments help in improving the overall quality of the life by embedding various Information Communication Technologies (ICT) in assisted living to ensure the needed health care and other services in a safer, secure and intelligent ways [90].

With the inclusion of various ICT's in assisted living, telecare and remote surveillance AAL applications have emerged as an important research topic in this domain. WASN's is a group of wireless microphone nodes playing a crucial role by providing non-invasive and non-obtrusive monitoring technologies in an indoor environment. Along with WASN's, cloud computing especially fog computing have been contributing to reducing the cost and requirements of surveillance platforms by offloading the heavy computation and storage tasks associated with healthcare monitoring to the cloud [91].

The performance of AAL systems can be amplified by the inclusion of cloud computing [2]. Rashed et al [92] proposed a cloud-based IoMT platform that is multi-layered for monitoring patients in an AAL environment that alleviates the need for unnecessary doctor visits, and cuts down on hospital stays and re-admissions whenever possible. The proposed multi-layer architecture collects information about the patient vitals and alongside his/her surrounding environment, sends this information to a cloud for storage and data analysis and then this raw data is transformed into useful information for both the caregiver and the patient.

A more advanced form/example of AAL environments were discussed in a strategic research project 'The Naked Approach' [93], [94]. The key idea behind the gadget-free world (also known as the naked world) is that users can access the needed digital services (including health care) from the smart, intelligent and ambient nearby environment in a ubiquitous manner and without the need of the hand-held gadgets (e.g., mobile phones, laptops and tablets etc.) [95], [96]. Services, technologies and required computations and communications capabilities will be embedded in the smart surroundings and they will appear when needed and disappear when not required. Moreover, the work presented in [97], [98] have discussed the gadget-free and ambient health care and proposed biometrics-based authentication mechanism for the users.

C. ELECTRONIC HEALTH RECORD SYSTEMS

From the perspective of physicians and the nurses, an electronic health record (EHR) system is a tool for information management and knowledge management bringing together the information needed to care for a patient in one place [39]. An EHR system is a platform for other digital subsystems. It acts as a recorder of care information and in sharing the information collected with others involved in care, transcending time and place boundaries. The information thus includes temporal patient data and can be used in different institutions involved in care in different geographical locations according to the principles of the care chain. In countries with a national health information exchange, patient record data forms a person's lifelong health history [99]. Because of this wide coverage, which is not limited to a single institute, the term electronic health record is nowadays used more and more instead of earlier terms like electronic medical record or electronic patient record which were best suited describing a patient information system restricted into one institution.

The patient is also involved, since he may be sharing his own knowledge. EHR systems include also care logistics, the patient's path through the service system, and the necessary resource management. Similarly, EHR systems include the storage of statistical and transactional data and thereby local and national performance and quality control and monitoring. An increasingly important part of patient information systems is knowledge management and the ever-evolving intelligent decision support systems and various alert systems [100]. Inside the EHR systems, tools have been built for communication between those involved in treatment and also for communication with patients.

In fact, EHR systems are always a family of different function modules and number of components depends on the number of functions required in each facility / environment. The function modules are then assembled around the core patient information system of different brands. In the public debate, these two completely different things are often confused: 1. how many core patient information systems do we have and on the other hand 2. how many different functional modules have been assembled around those core systems. For example, there are only a few core patient information systems in Finland [101]. Thus, it is reasonable to develop functional modules that can be integrated with those core systems.

The other functional modules have been assembled around the ''onion core'' of that core system, such as e.g. a medical imaging system, laboratory system, biosignal recording system, electronic referral, operating room workflow control, catering, care appointment reservations, anesthesia and intensive care unit system, blood bank management, and cancer treatment planning [102]. It is necessary that these ''layers of onion'' can be added and modified as needed. Not all users use all of them, but the use is depending on the medical specialty or other professional role.

On the other hand, national regulations must ensure that core systems comply with the international standards and industry specifications and that information is thus fluently exchanged between them [103]. The same obligation to comply with the standards applies to the exchange of information between the core system and the ancillary ''onion layers'' around them. Finally, all systems must be able to exchange information in a secure format and build safeguards against cybersecurity threats [104].

A specific challenge with remote care solutions is their connectivity with master EHR systems. To be useful for health professionals, the data obtained from various sensors, IoT devices and mobile health applications should be integrated to the data already available in the EHR and displayed seamlessly with existing institutional health data. There is still lack of both technical and semantic integration. A recent study analyzed 362 different mobile health monitoring devices and found that only few systems have a Conformité Européene (CE) marking class II or above, or approval from the US Food and Drug Administration (FDA) [105]. The study revealed also that only few systems support health middleware. There have been various studies discussing possible solutions to provide a standardized and secure model for data transfer from sensor level to EHR level, requiring a multiple tiers in data management [106] [107]. For healthcare professionals an additional challenge is the quality of information, unprocessed data is rarely useful and its analysis consumes time resources. Novel solutions are needed to display within the EHR interface only medically relevant information as well as findings which require action from physicians or from nursing staff members.

Positive user experience has a pivotal role in the success of electronic health records and related remote care applications. In this regard, physicians and health care professionals pay attention to the technical functionality and speed of systems, usability and user experience in their daily work, data presentation, patient safety and quality of care, up-to-date access to medication data, and the efficiency and information flow between stakeholders [108], [109]. In the future, it is expected that the data already stored in the systems will be used for clinical decision support, treatment guidance, planning and quality control without re-entry [110]. For example, in the case of chronic diseases, such as diabetes, information systems can provide early warning of the need for preventive measures at the population level. Various situation-specific risk warnings and remarks also increase patient safety.

D. BIG DATA MANAGEMENT AND ANALYTICS

In today's digital world, massive amounts of data are generated daily at an unprecedented rate from a wide range of sources (e.g., health, government, social networks, marketing, and financial). The data generation is linked to a number

TABLE 4. A comprehensive list of open source big data analytics tools and their applications in healthcare.

Tool	Short Description and Advantages	Healthcare Applications	Link
Apache Hadoop	An open-source software framework that utilizes clustered file system to efficiently store and process big data using the MapReduce programming model. * Quick access to data due to HadoopDistributed File (HDFS) System. * Highly scalable and cost effective.	- Patient classification and disease diagnosis [118] - Healthcare intelligence [119] - Application in geonmics [120] - Digital health big data processing [121]	http://hadoop.apache.org/
Apache Spark	Apache Spark is an open-source, powerful data processing and analytics engine. Spark provides an interface for complete programming clusters with implicit data parallelism and fault tolerance and for interacting with other Spark components. * Quicker batch and stream processing. * Ease of transformations. * High compatibility with various tools.	- Classification of cancer stages [122] - MRI analysis [123] - Predicting healthcare resources for effective utilization [124] - Diabetes Prediction [125]	http://spark.apache.org/
Apache Storm	An open-source data computation system with real-time computation abilities. * Can be used with numerous programming languages. * Simple implementation. * Consistent at scalabiity. * Fault-tolerant.	- Real-time healthcare analytics [126] - Distributed healthcare monitoring system [127] - Patient monitoring system [128]	http://storm.apache.org/
Apache Mahout	An open-source project used for the implementation of scalable machine learning algorithms such as classification, clustering, etc. * Compatible with Hadoop libraries to effectively scale the cluster. * Provides ready-to-use frameworks for data analysis on big data sets. * Analyzes big data sets faster and effectively.	- Big data healthcare analytics [129] - Disease progression and predictions [130]	http://mahout.apache.org/

of technological trends, including the IoT, the growth of cloud computing, and the proliferation of smart devices [111]. Behind the scenes, robust systems and distributed applications support such systems with many connections (e.g., smart grid systems, health care systems, retailing systems). In the current technological era, the need for big data analytics is emerging due to the increasing volume, velocity, and variety of data being generated by smart devices in almost every domain. The digital data sources and the requirement for data analytics in the health care industry, in particular, are growing due to the rapid advancements and acceptance of digitalization.

The storing of health care data on remote servers or cloud-data centers has traditionally been implemented using database systems, such as Google cloud, SQL, Oracle, etc. These conventional database systems are mainly seen as tools for permanent storage of the patient's data. Today, the health care data is, however, growing with enormous pace, not only because of its volume but also with the diversity of the data types. Handling real-time medical big data collection and storage in health care systems is becoming more and more challenging. Furthermore, data repositories are growing in complexity, not only by the volume, velocity, variety, but also by veracity due to the inconsistency of data [112]. Health care domain includes many application scenarios with, e.g., intelligent analysis functions, where the gathered raw data is needed only temporarily. In these scenarios, the data between different system components need to be manipulated as dynamic data flows instead of storing as static data items. Traditional database management systems lag in performance and are inefficient in handling this dynamic big data in terms of cost and time [113]. In contrast, event streaming technologies allow data manipulation on the fly. Apache Spark and Apache Kafka are the most popular event-driven architecture used for processing the stream data with aim to provide a unified, high throughput, and low-latency platform [114]. It is interoperable with different DLT technologies and architectures, and therefore, it is a promising technology for providing the needed reliability and trustworthiness in mission critical and data-intensive health care applications.

Big data analytics can provide an effective platform equipped with state-of-the-art tools and techniques to answer various data management and analytic challenges related to health care applications [115], [116]. As a result of the emergence of big data analytics and its accompanying technologies, the health care industry went through several significant developments. A comprehensive list of standard big data analytics tools and their applications in healthcare sector is presented in Table 4. Yet another motive for using big data analytics-based health care intelligence systems is to help individual practitioners or medical teams make data-driven decisions in seconds to improve patient's health. With the use of specific outcomes based on available/historical data; such as i) length of stay (LOS), ii) patients who are likely to benefit from surgery or not, iii) extreme complications, iv) hospital-acquired illness; v) illness/disease progression;

vi) factors of illness/disease progression and vii) any other unfortunate encounters, more results can be predicted, and insight can be generated related to patient's health [117].

The benefits of big data health care in real-time applications can further be categorized into three sub-categories, i.e., a) better patient care, b) enhanced doctors experience c) less organizational efforts [131]. The list of possible benefits/ motivations of using big data health care are as follows,

- Predict the patients centered conditions
- Prevention of any uncertain conditions
- Extensively research and development to cure diseases
- Encourage to use of Electronic Health Records (EHRs)
- Enhance patient-engagement
- Use predictive analytics
- Alert generation for instant care
- Health data analysis for strategic planning
- Fraud reduction and data security enhancement
- Reduce unnecessary visits or emergency room visits
- Integrating medical imaging for better diagnosis
- Smart and better staff management
- Doctor's/medical-staff's learning and development
- Self-harm and suicide prevention
- Help to develop new inventions
- Reduce managerial cost

Big data promises enormous prospects and transformative potential for the health care sector, but on the other hand, it also creates unique challenges for exploiting such massive volumes of data. Big data analytics in health care is still a challenging task for a number of reasons, i.e., the complexity of big data with respect to its volume, velocity and variety, the requirement for scalability, and the capacity to evaluate such massive heterogeneous data sets in real-time [132]. To truly understand the association between features and to examine data, advanced data analysis tool and techniques are required. Numerous big data models, frameworks, and new technologies have been developed so far as a result of several big data projects worldwide to increase storage capacity, parallel processing, and real-time analysis of various heterogeneous data sources. A comprehensive list of widely known health care big data analytics-based solutions are shown in Table 5.

TABLE 5. A comprehensive list of big data analytics solutions for health care.

Commercial Solutions	Short Description
IBM Watson Health [133]	Provides clinical and health-related data-sharing and analytic facilities for improved research and decision making.
MedeAnalytics [134]	Provides performance management solutions, health systems, programmes, and analytics, as well as patient data.
Health Fidelity [135]	Provides strategies for optimizing and adjusting risk management in health care work-flows.
Roam Analytics [136]	Provides NLP-based platform for health care systems and platforms for analyzing large unstructured health care datasets to extract meaningful insights.
Flatiron Health [137]	Provides services for oncology data for better cancer treatment.
Enlitic [138]	The Enlitic Curie™ platform contains a number of AI-powered tools for reading, reporting, quality assurance, and research, all of which automatically standardize data for health care diagnosis.
Digital Reasoning Systems [139]	Provides services and data analytic solutions for processing and organizing unstructured data into relevant information.
Ayasdi [140]	Provides an AI-enabled platform for analyzing clinical variance, population health, risk management, and other aspects of health care.
Linguamatics [141]	Provides a text mining system for extracting meaningful insights from unstructured health care data.
Apixio [142]	Provides a platform for cognitive computing to analyze clinical data and pdf health records in order to generate in-depth information.
Isabel [143]	A clinical decision support tool that provides health care professionals access to an online system that assists them to make an accurate diagnosis quickly. It consists of over 6000 diseases and conditions.
Practo [144]	A comprehensive health application for scheduling doctor visits at clinics and hospitals, ordering medications, setting medication reminders, consulting doctors online, managing digital health data, and reading health recommendations.
Lumiata [145]	Provides analytics and risk management services to ensure efficient outcomes in health care.
OptumHealth [146]	Provides a platform to improve current health care system infrastructure with health care analytics and create progressive and unique solutions for the health care business.

E. DISTRIBUTED SERVICE ARCHITECTURES

At present, the solutions for home remote healthcare are mainly based on hybrid clouds, and different medical services are usually provided according to the type of community or hospital. With the development of 5G, AI and other technologies, distributed healthcare services that are suitable for massive device access and heterogeneous data integration through edge computing platforms have become research hotspots.

1) HYBRID CLOUD SERVICES

Cloud computing has brought endless benefits to the health care industry, and many hospitals and research institutes have already migrated their businesses to the cloud [147], [148]. Currently, not many health care providers are enthusiastic on using public clouds. Instead, these institutions prefer to use hybrid cloud services to jointly utilize internal private data centers and third-party public cloud services [6]. In this situation, service providers can supply and schedule medical resources for remote health care, as discussed below:

- **Improve patient care services:** As a hybrid cloud application, the Smart-Evac [149] provided immediate remote health care facilities as well as ambulatory medical services for patients. Users can share,

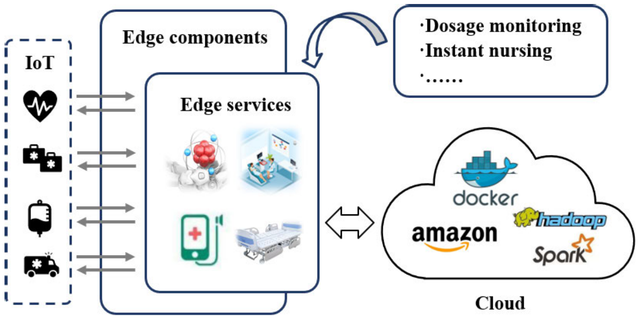

FIGURE 4. The basic architecture of cloud-edge platform for remote home care.

view and store their records in the cloud, and doctors can also archive and access them remotely. By putting documents in the cloud, different medical centers can access patient data with the push of a button without worrying about endless paperwork and delayed treatment. Based on this, a personalized knowledge discovery framework has been implemented for assisted health care [150].

- **Unleash medical resources:** By using hybrid cloud services, health institutions can expect better resource allocation. Excellent service quality of medical treatment when scheduling, recommending, purchasing documents, inventory management, and many other types of back-office operations can be ensured [151]. For instance, an IoMT-based cardiovascular health care system implemented by [152] made the on-patch compression ratio of the raw ECG signal reach 12.07 yielding a percentage root mean square variation of 2.29%, by using a cross-layer optimization from sensing ECG patch to cloud platform.
- **Paving the road to smart healthcare:** The hybrid cloud comes in handy when the healthcare task needs a large amount of computational resources. By hybrid cloud, medical practitioners can analyze the genomics data and gain a deeper understanding of the causes of breast and ovarian cancer [153]. Moreover, computing and data resources provided by hybrid cloud can be exploited to run AI algorithms [154].

In recent years, more and more smart terminals have been introduced into the medical environment, including wearable devices [155], [156] and health monitors [157], [158]. Wearable devices can allow clinicians to learn vital signs of critical patients, such as heart rate and blood pressure, and alert patients before health problems occur. Health monitors can collect patient data and trigger corresponding actions based on the results to help telemedicine services. Whether it is remote surgery, remote consultation, remote teaching, etc., a huge amount of data needs to be transmitted, and some of the applications are extremely sensitive to time delay. In order to meet such needs, it is necessary to deploy edge nodes in the hospital [159], as elaborated below.

2) EDGE COMPUTING

Edge computing brings data processing, analysis, and storage closer to the source of the data. It can keep personal or sensitive data local, and health systems and health service providers can comply with strict standards. With the help of edge computing technology, the health and life sciences industries are now forming a novel medical service delivery strategy, that is, strategically adopt cloud and edge computing according to needs, costs and benefits in order to help the health system optimize data collection, storage and analysis. Since it cannot be expected that local IoMT clusters have sufficient devices with sufficient stability and hardware capacity to run a full-fledged edge server, decentralized solutions fitting better to the capacity-constrained environments than dedicated edge servers are needed. Literature [160] proposed and evaluated a two-tier IoT edge architecture with the serverless edge computing model for local service provisioning. In [161], the authors utilized a serverless computing paradigm to implement a container-based lightweight microservice architecture to extend the edge computing paradigm with a local tier (third tier, allowing local decentralized deployment of lightweight edge services, called nanoservices. Local serverless edge computing enables a wide variety of cloud service functions to be deployed on local edge nodes in a distributed manner, which is a promising solution for the health care domain as well.

F. ARTIFICIAL INTELLIGENCE

Among the most important trends in moving towards the next generation health care systems, AI techniques have a vital role [162]. Since medical systems are evolving along with technologies for connectivity, i.e, the 5G telecommunications, most health care systems are digitized and interconnected. The result is abundance of data that can assist the healthcare professionals in a variety of ways. AI has, thus, a key role in analysis of data for meaningful results. Furthermore, AI has also been embedded into latest medical equipment to assist the healthcare professionals in performing complex tasks, and provide medical assistance and remote health care [163].

AI has a wealth of application cases in the field of health care, which can not only assist radiologists in analyzing medical images, but also assist in monitoring patient status [164]. Currently, there are more than 64 kinds of AI-based medical instruments and algorithms approved by the US Food and Drug Administration, many of which have been integrated into the clinical care [165]. Existing AI algorithms, especially deep learning algorithms, have achieved human-level accuracy in the recognition and analysis of certain disease specific data from source material such as CT, X-ray, MRI or bone density scan images, and electrocardiogram [166].

Li *et al.* [167] realized the first privacy protection federated learning system for medical image analysis; Tencent Tianyan Lab and WeBank AI team jointly developed a "stroke risk prediction model" based on the medical federal learning framework [168], using AI technology to process electronic medical records, the accuracy of stroke risk prediction is as high as 80%. Besides, AI virtual fences can detect the position of the baby, alarm when playing alone at the bedside, or comfort with breathing lights and music [169], [170]. And also, the clinical voice recognition system replaces nurses in recording the needs of patients, with an accuracy rate close to 95% [171]. According to sensory categories, the existing cutting-edge medical AI applications are listed in Table 6.

TABLE 6. Available AI technologies for healthcare.

Sensory categories	Learning algorithms	Scenarios
Machine visual	Deep Boltzmann Machine [176]	Intraepithelial Lesion
	Auto-Encoder [177]	Cell carcinoma
	CNN	Lymph node detection [178], [179]
		MRI Denoising [180]
		Skin cancer detection [181]
Voice recognition	DNN	Hearing aid [182]
		Baby crying [183]
	Bi-ResNet	Respiratory Disease [184]
	DeepCough	Covid-19 Test [185]
Electroencephalogram	CNN, RNN, DBN and Auto-encoders	EEG classification [186]
Other health indicators	Body temperature measurement	Covid-19 Test [187]

In order to achieve the prevention and control of highly infectious diseases such as COVID-19, global scientists have developed a large series of AI-based non-contact body temperature detection [172], unmanned meal delivery [173] and other equipment and application platforms [174]. In addition, the Brazilian have developed an electric wheelchair device that is manipulated by facial expressions in real time based on the Intel OpenVINO open visual reasoning and neural network optimization toolkit [175]. The maximum delay of the entire system does not exceed 100 milliseconds, which can significantly improve the mobility of the disabled.

G. 5G

5G is playing an important role in providing distributed patient-centric health care systems through enabling connectivity of the digital health care systems [32]. The capabilities of 5G to address the requirements of smart health care systems, such as extremely low latency, high bandwidth, and reliability, are discussed in [32]. High densities of access networks have increased and smoothed connectivity between smart health care appliances. Furthermore, the novel technologies used by 5G such as the integration of the concepts of cloud computing like edge and fog computing have provided opportunities to locate privacy and latency-sensitive services in the health care vicinity. Similarly, softwarized and virtualized network functions and services have simplified mobility of sensitive services into and between health care environments [188]. For example, the CURATE platform proposed in [188] uses cloud platforms to instantiate new services in the health care location to meet the latency and privacy requirements, and uses virtualization and slicing for resource isolation. Such techniques can also be used in remote home care to provide latency sensitive services being isolated from each other, yet on the same infrastructure.

5G has increased the capabilities of remote care providers through enabling optical communications as discussed in [189]. The article elaborates how remote health care providers can leverage on the higher bit rates, low latency and reliability of 5G to provide visual assistance. A robot fixed with optical camera communications systems connected through 5G enables monitoring and remote assistance in homes, ambulances, hospitals, intensive care units and outdoors. The proposed architecture [189] can provide help to multiple patients simultaneously, mainly capitalizing on the higher bandwidth offered by 5G networks. Similarly, extremely sensitive to latency- telesurgery using 5G has been evaluated in [190]. The telesurgery has been enabled by the ultra-low latency communications [191], [192] in 5G that allows precise remote control of robotic instruments, and high bandwidth enabling 3D visualization of the surgical site. Specific to the higher bit rates compared to 4G, for instance, 5G provides data rate that can fulfill the requirements of medical imaging and its online exchange as discussed in [193]. Such capability is of particular need for remote care where high dimensional figures and data from terminals in the user vicinity are needed by remote caregivers or doctors.

As discussed in subsections V-H, 5G provides the necessary coverage with sufficient reliability, security and bandwidth for the mobile health units, IoT and IoMT, WSNs, and BANs. The most pertinent use-case for 5G, however, will be monitoring patients in outdoor activities, where other access and connectivity technologies will have limited or no reach. Wearable devices implanted into recipients of remote care can be connected to the monitoring and care systems or remote caregivers through 5G. It is envisioned that future care recipients will leverage the development in wearable and connectivity technologies to seamlessly access and use services without actively seeking for it [194], and 5G fills the gap through connecting heterogeneous devices to each other and to centralized systems. Furthermore, the integration of satellite systems into 5G [195] has opened new opportunities in terms of providing care where there is no terrestrial infrastructure or is damaged [196]. For example, ships, island, and many underdeveloped countries in terms of network infrastructure can all benefit from non-terrestrial networks. Satellite networks have been considered as part of 5G by the 3rd Generation Partnership Project (3GPP) [197], as standardization body, and the EU-5G Public-Private Partnership (5GPP) organization [195].

There are also other 5G technologies that are specifically helpful in providing the health care services in a reliable manner. One of the most promising technique that has been

TABLE 7. Selected wireless connectivity technologies and their illustrative performance metrics.

	Backscatter	Short-range wireless & IoT		URLLC	UWB	BAN		Broad-band	mMTC & LPWAN			Satellite		
Technology	RFID	BLE	802.11 ax	DECT-2020	802.15.4z	802.15.6	SmartBAN	4G	NB-IoT	LoRaWAN	SIGFOX	NTN 5G	Inmarsat M2M	Iridium M2M
Deployment status	available	available	available	in development	available	in development		available	available			in development	available	
Standardi- zation body	multiple	Bluetooth SIG	IEEE	ETSI	IEEE	IEEE	ETSI	3GPP/ ETSI	3GPP/ ETSI	LoRa alliance	proper	3GPP	proper	
Frequency band	multiple	2.4 GHz ISM	2.4 & 5 GHz ISM	1.9 GHz DECT	2.5-6 GHz ISM	0-10 GHz	2.4 GHz ISM	400 MHz-6 GHz licensed	700-2200 MHz licensed	sub GHz ISM		TBD	1600 MHz, L-band	
Average consumption when active[1,2]	passive	units mW	hundreds mW	not available	dozens mW			hundreds mW	dozens mW			TBD	hundreds mW	
Range	meters	hundreds meters	dozens meters			meters		units kilometers	units-dozen kilometers			global		
Maximum throughput[1,3]	hundreds kbit/s	units Mbit/s	hundreds Mbit/s	units Gbit/s	hundreds Mbit/s	units Mbit/s		hundreds Mbit/s	dozens kbit/s	units kbit/s	dozens bit/s	TBD	dozens bytes per second	
Typical latency[1]	units ms	dozens ms	units ms	below one ms	units ms			dozens ms	hundreds ms -seconds		units seconds	TBD	dozens seconds	
Potential elderly-care use case	(i) track, (ii) sense	(i)IoT data, (ii)track, (iii)sense	(i)IoT data, (ii)track, (iii)sense, (iv)stream	(i)critical, (ii)stream	(i)IoT data, (ii)track, (iii)sense	(i)critical, (ii)IoT data, (iii)track, (iv)sense		(i)IoT data, (ii)track, (iii)stream	(i)IoT data, (ii)track			(i)IoT data, (ii)track, (iii)stream	(i)IoT data, (ii)track	

[1] Based on the data-sheets of state-of-the-art commercial chipsets and research literature.
[2] Peak consumption in a typical operation scenario.
[3] Peak physical-layer (PHY) throughput.

brought forward with 5G is network slicing and enabling service specific verticals [198]. With such approaches resources over the network can be dedicated to provide slices that are independent of other services and are isolated to provide reliability and security. Different medical devices, systems, and networks can be provided its own slice in a dynamic fashion in order to maintain privacy and independence on one hand, and extend operations without incurring extra costs in infrastructure, on the other hand. The concepts of multi-access edge computing (MEC) brings computation and storage closer to the remote care vicinity to further facilitate localized computing and storage to avoid network latency in critical applications [199], and improve security and privacy of important user information [200]. MEC has also been proven helpful in deploying and using AI techniques in the remote care facilities.

5G has security challenges on the general level, as discussed in [201], [202] which can be problematic in the case of remote health care due to its sensitive nature. Therefore, an automated zero-touch security systems for remote health care in 5G has been proposed in [203], which is further discussed inV-M1. However, end-to-end security in 5G must be ensured for remote health care overcoming the vulnerable nature of distributed and wireless systems. Security and privacy for remote healthcare are further discussed in subsection V-M1.

H. INTERNET OF MEDICAL THINGS

Likewise the non-medical IoT, the IoMT is very diverse and heterogeneous when this comes to applications, architectures and even the underlying technology background. To illustrate the latter in Table 7 we summarize the selected existing and prospective non-proprietary radio access technologies, which can be employed in remote healthcare and assisted living.

The devices belonging to the IoMT can be categorised into three main categories with respect to their location relative to the patient or the human user and role. The former group, which we refer to as BANs, wearables and implants, implies positioning of an IoMT device either on the human body or, in some cases, even inside of it. The second option, which we name Environment Sensor and Actuator Systems composes the IoMT devices located in the environment around a human, and which can be either static or dynamic. Finally, the last group of devices composes the versatile IoMT devices serving as a part of the infrastructure, providing communication, implementing data storage, processing and security, carrying decision making, and even delivering power to the devices of the two former groups. Very often these devices also feature more resources (e.g., processing power or energy) than the ones belonging to the two former groups. Note, that the provided classification is non-ambiguous and some devices (e.g., a mobile phone) might be attributed to the different categories. This is also important to note that to distinguish between wearables/BANs and external sensors/actuators, which might get in temporal contacts with a human body (e.g., a smart matres) we further imply that wearables/BANs move together with the human. However, we have to admit that this classification is rather conditional and some IoT devices (an infrared thermometer to give just one example) might transition between these two categories in the process of its use.

In what follows, we provide a more detailed discussion of the two former categories of devices, including their real-life application examples, which are summarized in Table 8. The table lists illustrative elderly-focused smart health care

TABLE 8. Field demonstrations and prototypes of elderly-care devices involving use of the different RATs in state-of-the-art literature.

Ref.	Year	RAT(s)	Environment	Backbone connectivity and data presentation	Purpose/use case
Body-External Sensor and Actuator IoT Devices and Systems					
[204]	2021	RFID	Home, hospital	Not detailed	An activity-classification system based on analysing the radio channels between a stationary reader and multiple stationary tags.
[206]	2021	UWB	Home	Not detailed	An activity-classification system based on UWB radar.
[207]	2020	WiFi	Home	Over Internet. Server with UI for user and caregiver.	Medicine (pill) box tracking consumption of pills.
[208]	2020	WiFi, BLE	Home, hospital	Over Internet. Server with UI and notifications for user and caregiver.	Bed-integrated sensor for fall and bedsore detection.
[209]	2020	WiFi	Home, hospital	Not detailed	Bed matt for bed occupancy and urinary incontinence detection.
[210]	2020	LoRa/LoRaWAN	Home	LPWAN backbone and Internet. Server with UI and data base for assistant/volunteer.	A device collecting transportation requests from elderly and delivering these to an assistant/volunteer.
[211]	2020	N/A	Home	Not detailed	A remotely controlled drone used for contactless delivery of medicines to elderly.
[212]	2019	WiFi	Home	Not detailed	Activity and respiration status (e.g., respiration apnea detection) monitoring through analysis of channel fluctuations of commodity WiFi.
[213]	2019	WiFi	Home	Not detailed	A mobile service robot with emergency and social assistant functionality.
[214]	2019	Not detailed	Home	Over Internet	A mobile robot with interface to physician for engaging elderly in physical exercises.
BANs, Wearables and Implants					
[215]	2021	RFID	Home, hospital	Not detailed	RFID tag allowing for breath patterns monitoring.
[216]	2021	Bluetooth, Cellular	Home	Not detailed	A shoe with integrated sensors for physiological. parameters.
[217]	2021	RFID	Home, hospital	Over mobile Internet. Phone application for caregiver.	A system for tracking and localizing patients.
[218]	2020	WiFi	Home	Not detailed	Glasses-integrated sensory system for accidental fall detection.
[219]	2020	UWB, ZigBee	Home	Not detailed	A watch tracked through TDOA of signals to anchors for fall detection.
[220]	2019	Not detailed	Various	Not detailed	An overview of exoskeletons supporting elderly mobility.
[221]	2019	proprietary	Home	Not detailed	Wearable sensors measuring physiological parameters and gateways to collect these data.
[222]	2019	NB-IoT	Outdoors	Over Internet. Dedicated application server.	Fall detection and location tracking device.
[223]	2019	Not detailed	Various	Not detailed	A robotic cane for balance maintenance assistance.
[205][1]	2018	BLE	Home	Local over BLE. Smartphone app with notifications.	An urination detector for smart diapers.
[224]	2016	BLE	Home	Local over BLE	VR Gaming application controlled from BAN for motivating elderly mobility.

[1] Even though the diaper has been originally proposed for children, we consider that a similar solution can be used for elderly.

devices, which have been suggested and reported in the research papers [204], [205] during the recent years. Note, that we intentionally limited the discussion to the devices, which have been prototyped and validated in hardware, thus going beyond the concept or proof-of-the-concept phase. In addition to the reference and a short description of the proposed system or device, we list the intended environment of operation and the radio access technologies (RATs) used.

1) BODY-EXTERNAL SENSOR AND ACTUATOR DEVICES AND SYSTEMS

This subgroup composes versatile IoT devices (i) monitoring or (ii) interacting with an elderly person or the environment or its element(s) located around. Note, that in the process of monitoring and interaction an IoT device might either get in direct contact with a human or not. Also the operation (and even the presence) of the device might be imperceptible to a user or even require some action or cooperation from him or her (e.g., stay still while the breath pattern is being measured), to list the two extreme cases.

In the case if the intended operation environment is static and controlled (e.g., own home or a hospital ward) the use of body-external IoT devices, which can be placed stationary and seamlessly integrated in the objects of the environment, is especially beneficial. The less stringent requirements for device's weight and dimensions compared to wearable devices, the availability of non-intermittent power supply and established connectivity services, and infrequent change of the environment - all these factors affect the design choices and applications of such devices. Specifically, connectivity-wise these devices can rely on the already-deployed wireless technologies, such as IEEE 802.11 family of standards (i.e., the WiFi) for backbone Internet connectivity or Bluetooth for local connectivity. However, in the case if an application imposes more sophisticated or additional requirements (e.g., the need for accurate localization, ultra-low latency or the highest degree of reliability), the other connectivity approaches can be employed. Notably, for the majority of the today's home-monitoring applications the topology of the wireless network is still either stars/star-of-stars, or even peer-to-peer, while the use of a mesh topology is rather rare. However, with the increase of the size of the deployments (e.g., to hospitals, block-of-flats houses dedicated for elderly or even towards the applications employing city/scale coverage) the mesh-based solutions might find some use-cases, despite their more complex management.

Notably, during the recent years there have been proposed a number of novel non-invasive solutions, allowing to monitor the different physiological parameters by a dedicated sensor with no contact to human body (e.g., through employing radar-like technologies or machine vision), or even without using a dedicated sensor at all (e.g., through analyzing the fluctuations of a measured radio channel of a conventional communication system like WiFi). Such systems, which (i) need minimal service after being installed and powered from mains, and (ii) run in the background not interfering the daily routines of their users and not requiring any action or learning from a user, might be especially beneficial for elderly-care scenarios at their homes.

Specifically, the IoMT devices for elderly care use cases have been proposed by the authors, e.g., in [207]–[210]. The study [207] prototypes a medication (e.g., pill) box which automatically logs the time when medicines were taken and, if needed, reminds the user of taking the prescribed medicines. The box is connected over WiFi-based Internet connection to a dedicated server, which provides a web-based user interface for the user and caregiver/doctor. Pongthanisorn *et al.* [208] developed a sensory system to be placed under the bed mattress for classifying the position of a person in a bed and following his/her movement. The collected data are first delivered over BLE to a concentrator device, which forwards them over Wi-Fi-based Internet backbone to a server, which visualizes them and may generate some notifications (e.g., for a caregiver). Another bed-integratable solution was proposed in [209]. The sensory system detects the occupancy of a bed, and can detect and signalize to a caregiver urinary incontinence events. The devices developed by Sano *et al.* in [210] provide an interface for an elderly person to request a transportation service. The user specifies the desired destination and time of departure, which are further delivered through LPWAN technology to a server of special service or volunteers. Notably, the use of LPWAN-based connectivity allows to deploy the devices even in households not connected to the Internet. Note, that the solutions reported in [204], [206], [209] focus specifically on sensoring and do not address visualization of the data or their delivery to an end-user.

In contrast to the previously discussed, the solutions reported in [204], [206], [212] imply no direct contact or interaction to a human user. In [204] the authors introduce a setup composed of multiple RFID tags mounted on a wall and a single reader. Through measuring the state of the radio channel between the reader and each tag and employing deep learning methods, the conceptualized system detects the presence and identifies the activity of a human located between the reader and the wall-mounted tags. The authors of [206] utilize a statically-placed UWB radar in indoor environment for (i) detecting the presence of a human user, (ii) determining user's activity, and (iii) analyzing user's breath pattern. The authors of [212] analyze the fluctuations of channel state information (CSI) signal of commodity WiFi to detect the presence and activity of a user. They also demonstrate that the analysis of CSI enables detection of user's respiration status and respiration apnea events.

This is worth noting that besides the activities in scientific community some of which we have pinpointed above, the relevant ideas and models are also developed by businesses and civil services. To illustrate for this, in [211] is reported a contact-less drone-based medicine delivery system for elderly in their homes. Unfortunately, the technical information about the design of this solution is quite scarce. Another mobile robot, which can serve as an emergency and social assistant to elderly has been designed and reported by the authors in [213]. A socially assistive robot aimed at engaging and guiding the elderly in the physical exercises has been introduced by the authors in [214].

2) BANs, WEARABLES AND IMPLANTS

Deployment and operation of a radio-communicating device next to or even inside a human body introduces a number of specific challenges, due to which we categorize the respective devices into a standalone group. First of all, these are the specifics of radio channel propagation inside and next to a human body [225], [226]. Second, these are the regulatory aspects intended to ensure safety of a human exposed to elecro-magnetic radiation next or inside the body [227]. Finally, the design (and, particularly, ensuring safety and reliability) of a device located inside the human body is quite tricky.

The devices belonging to this group can be subdivided further into two subcategories. The former ones imply just a temporal operation near to human body (e.g., a wireless endoscopy capsule, a blood oxygen saturation sensor mounted for a single-time measurement, or a smart diaper) lasting for seconds to hours. The latter group composes the devices intended to stay with a human for days or years we denote as continues. As examples of these may serve: (i) a pacemaker or insulin pump implants, (ii) a water-proof smart ring or a smart bracelet for measuring various physiological parameters, serving as a key, or for identification. Notably, the devices belonging to the second group have to handle and support all the possible mobility of its user, which makes the design of such devices and, especially, selection of a connectivity technology much more challenging. For this reason, some of the discussed in what follows practical applications base on the assumption a device might have to operate during specific periods of time either semi-autonomously or completely autonomously.

Due to all the obvious challenges associated with the development and validation of an implantable IoT device, this is hardly surprising that we were unable to find in the research literature any works matching our target criterion (i.e., having a validated implementation). We consider this fact to be a good illustration of how complex the development and, especially, testing of such a solution today is.

An RFID-wearable (integrated, e.g., in cloth) based tracking solution, providing a notification to a caregiver in case the patients leaves the pre-defined area, has been developed by the authors in [217]. Two another tracking and fall notification solutions have been suggested in [219] and [222]. Zhang *et al.* [219] shape their solution in a hand-watch-like wearable and equip it with the UWB time difference of arrival localization module, which determines the position of the user with respect to static UWB anchor devices. The wearable solution reported in [222] is primarily intended for outdoor use, for which reason the prototype utilizes the NB-IoT cellular technology and a GNSS module for positioning. In case a fall is detected from the analysis of IMU data an alarm, including the coordinates, is sent over NB-IoT based Internet connection to a special server. Another application benefiting from accurate localization has been suggested in [215]. The authors track one or multiple RFID tags integrated in the cloths of a user, and by analyzing the tags movement determine the breath pattern of its wearer.

Few other IoT-based wearable devices have been proposed by the authors of [216], [218], [221], [223]. In [216] the authors design a pair of shoes with multiple physiological sensors, a GNSS receiver and a cellular modem integrated in them. The shoes collect the information about the activity of the user, and, if detect some abnormal activity or a fall - notify the caregiver by an SMS. The authors of [218] integrate several inertial sensors into the glasses, which they use to detect the user's fall. If a fall is detected, the glasses can employ WiFi to convey a message to a caregiver. The key difference of the wearable designed by Ali *et al.* [221] is its power supply. The device collects the energy from the temperature difference between the skin of the user and the environment. The collected energy is used to power sensors, a microcontroller and a Bluetooth radio module, and broadcast the measured data to the specially-designed gateways. Another solution which we considered to be an interesting illustration, even though it focuses primarily on babies rather than elderly, has been reported in [205]. The study prototypes the smart diaper equipped with the sensors to detect and notify to the caregiver an urination event. A BLE-based peer-to-peer connection to the caregivers smart phone and a special application are employed to deliver the notification.

Due to the lack of connectivity in the original design the attribution of the solution reported in [223] and [220] to IoT might be considered arguable. However, we decided to include these devices in our survey due to their (i) non-triviality, and (ii) clear benefit to develop connectivity for them in a long-term perspective. Specifically, in [223] the authors suggest a single-wheel-enabled self-stabilizing robotic cane, equipped with sensors, actuators and processing power to facilitate the mobility of the elderly users. Approaching the same challenge from a different angle, Kapsalyamov *et al.* [220] overview the different exoskeleton-based devices capable of supporting elderly mobility. Finally, another worth-to-note wearable system for elderly has been reported in [224]. The authors conceptualized a virtual reality (VR) system with tactile BAN-based control for promoting activity of elderly though a UAV-simulation game.

I. LOCATION TECHNOLOGIES

Locating and tracking both people and objects can help significantly in remote home care. This helps making justified decisions, finding people in need of help and assisting professionals in their daily work. Positioning technologies enable location-aware healthcare systems to be used in homes and enable use of smartphone applications. Examples include remote monitoring of patients or even enabling use of robots to support elderly. A general architecture for human indoor positioning is depicted in Fig. 5. The positioning module is connected to the sensors, radio receivers and cameras and estimates current location based on that information. The main task of the navigation and tracking module is to calculate the route to the destination. It can be connected to the database that learns the most used routes and movement patterns of an individual that can be used also when detecting changes. Finally, user interface supports human-machine interaction, helping the user to provide input and requests to the system, then giving instructions back to her.

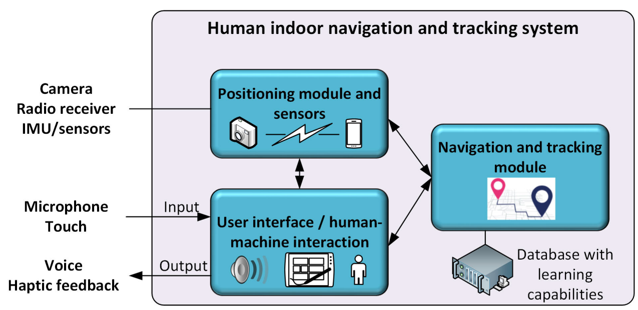

FIGURE 5. General architecture for indoor positioning.

We will review some technologies in following sections, focusing on indoor localization and providing references for interested reader to look further information. The set of technologies is not comprehensive one, there are additional technologies such as measuring strength variations in the measured magnetic field to infer a position estimate inside a building [228], [229], using Ultra–Wideband Impulse Radio (UWB IR) [230] or ultrasonic systems [231] that can be used with high accuracy in range-limited settings. However, we feel that the most important approaches for home care are covered.

1) GNSS

Global navigation satellite system (GNSS) technologies including Global Positioning System (GPS), GLONASS and Galileo are globally used for positioning [232]. They rely on satellite beacons mainly from satellites in medium Earth orbits (MEO) with highly accurate and tightly synchronized clocks. Galileo is a European system that is developing highly accurate services and public regulated services (PRS) to be used for demanding applications in coming years. PRS development aims at making Galileo positioning resistant towards jamming and spoofing. It will be mainly used by authorities for secure and reliable positioning. The GNSS technologies are also widely available as smart phone features, with apps linking location to databases indicating nearby services and structures. This provides powerful context information, when it is available. Lately use of low Earth orbit (LEO) satellites have been also studied in order to improve the accuracy of the systems [233]. However, satellite systems are seldom effective indoors and thus their use for remote care is mostly limited for providing information during outdoor activities or in assisting health care professionals to the place of need e.g. during emergency.

2) CELLULAR NETWORKS

Cellular mobile networks provide means for indoor localization, augmenting the satellite systems in 5G and 6G [234] where integration of terrestrial and satellite networks is expected [235], [236]. Cellular technologies include positioning based on received signal strength (RSS), direction of arrival (DoA), time of arrival (TOA) and time difference of arrival (TDoA) methods. Comparing to 4G, 5G has increased especially indoor positioning accuracy by adding new reference signals in NR specifications supporting both uplink and downlink positioning. Using multiple base stations and mentioned methods the positioning of e.g. a smart phone can be done more accurately than before, even down to 10 cm horizontally. However, the density of base stations and indoor channel models have an effect to accuracy that can be in practice in the order of several meters [237]. In 6G systems the aim is to increase the accuracy to the 1 cm level 3-dimensionally, i.e. including vertical direction in the design from the beginning.

3) WiFi

Highly dense WiFi networks can be used to improve indoor localization accuracy. A typical method is RSS fingerprinting where a position in space is determined uniquely by an ensemble of radio signal strengths. However, this does not take multipath propagation and penetration losses in a building into account, leading to inaccurate estimations. One of the improvements made lately is so called Fine Timing Measurement (FTM) that is a protocol in the IEEE 802.11 standard [237]. When FTM is used for mobile phone positioning, the phone performs range measurements with multiple access points (APs) that are placed in known locations. The range estimate is based on the round-trip time (RTT) of a signal's travel from an AP to the phone and back. With enough APs in place, accuracy of 1-2 meters can be achieved.

4) BlueTooth AND RFID

Another low-power technology used in the same unlicensed bands as WiFi is Bluetooth, especially interesting is the low energy version of it. As pointed in [238], its suitability is supported by the relatively low cost of emitters, their very low power consumption that let them run on batteries for months, and a generalized capability of modern smartphones to read their advertisements. In addition, radio frequency identification (RFID) is used for localizing objects with either passive or active RFID tags. Since readers are usually clearly more expensive than tags, a usual setting is to distribute large number of tags in the environment and attach the reader to the object (or person) to be localized [239]. Typically smart phones with near field communication (NFC) can read tags only few centimeters apart and thus, separate readers that can be linked to smartphone with Bluetooth are needed. This limits the use of technology for remote home care.

5) OPTICAL

Indoor localization with optical technologies can provide precise locations, however requiring always line of sight between the object and the localized persons or things. Different cameras and laser ranging technologies are used in robotics to evaluate surrounding and navigate in challenging indoor conditions. However, those devices can be quite costly. Thus, it has been evaluated also how to use low-cost devices such as Kinect multisensory device that has cameras and infrared laser projector for three-dimensional localization. It was originally developed for gaming but can be used also in medical applications and remote home care [52]. Kinect could be used to monitor the position, pose, movement and 3D parameters of a body in a quantifiable manner. Measurement of movement patterns and patient posture has applications in disease screening and detection of emergency situations which leads to better and faster health-care decisions in remote home care. Another example of infrared is the VIVE tracker that requires so called infrared lighthouses to be installed in the room of interest [240]. Each lighthouse is equipped with two lasers, which sweep across its horizontal and vertical axes. The infrared laser sweeps are detected by photodiodes which are mounted on tracker modules and difference in time arrivals is used to calculate the location.

6) DEAD RECKONING/ROUTE PREDICTION

Finally, a good way to increase positioning accuracy is to use dead reckoning (DR), which means estimation of the current position of a target based on a previously known position of it and advancing the position using estimated speed and trajectories [241]. One can use accelerometers found in modern smart phones that sense rotations and movements, or inertial measurement units (IMUs) typically mounted in feet and legs for pedestrian DR. Using the history information, input from sensors and Kalman filtering one can estimate trajectories and position. The predicted position can be used also in network resource allocations and automatic selection of the next access points to connect while moving [242]. If the DR is used as a stand-alone system, there is a risk of drifting over time and methods to overcome this are actively developed. When DR is used together with other technologies, accuracy can be increased significantly. When these approaches are combined with building maps it is possible to create assisting applications that help the elderly to find their routes and paths. The approach can be used in homes as well as in hospitals. Practical implementation of such a system is described in [243] where a person is carrying a wearable device at the waist. In addition, sensor fusion is done to improve accuracy.

J. DISTRIBUTED LEDGER TECHNOLOGIES

The use of distributed ledger technology into existing and future remote health care systems can bring various opportunities, such as managing identities of healthcare devices, establishing the provenance of data, preserving anonymity, automating payments, decentralized trust among devices and healthcare stakeholders, for example, trusted data sharing, etc. Blockchain-based smart contracts could offer a number of benefits such as fast, dynamic and real-time updates, automating operations and services in an efficient and trustful way. It automates the business processes with high accuracy and fewer intermediaries compared to current health care systems [244].

The transition of healthcare organizations towards enabling online services and EHRs has given rise to new issues in securing access to sensitive patient data. There is no mechanism for a patient to monitor whether their healthcare service provider is adhering to security and privacy rules [245]. Moreover, centralized Identity management and data storage remain more prone to hacking and data breaches [246]. The identity owner must have complete trust in their service provider in a centralized identity management system, leaving them with little or no control over their identity. If the system is hacked, the network may become completely inoperable. The distributed ledger technology allows for the distributed storage of records while maintaining security through cryptography. uPort [247], and Sovrin [248] are some examples of blockchain-based Identity management systems.

IoT can help health care to monitor a patient's health remotely through sensors. These sensors can continuously monitor and save health data on a server, allowing doctors to better understand a patient's status. However, medical errors might occur as a result of inaccurate data recorded by a faulty instrument. To record the health record on the ledger, decentralized blockchain technology can utilize smart contracts that register and verify the access rights of these sensors [249]. In the event of an emergency, smart contracts on the blockchain can transmit notifications to doctors and health centres.

TABLE 9. Comparison of traditional and blockchain supported telemedicine systems.

Parameters	Traditional telemedicine system	Blockchain-based telemedicine system
Privacy and Security	Hard	Easy
Cost	High	Low
Transparency	No	Yes
System Administration	Centralized	Decentralized
Auditing	No	Yes
Fault tolerance	No	Yes
Documentation	Yes	No
Data Provenance	No	Yes
Payments	Third-party	Integrated

An electronic health record contains sensitive and confidential information, that must be securely transmitted among hospitals, pharmacies and health authorities in order to keep a patient's medical information up to date [250]. Traditional health record management systems suffer a number of obstacles, including a long wait for health record exchange, a lack of trust in third-party servers, and the inability to conduct impartial audit trials. Distributed ledger technology can assist to enforce trust as no intermediaries are involved. It can provide a unified and consistent view of a patient's EHR and because of this transparency of records, the health care can recommend appropriate medical treatments. Blockchain technology can also be used to conduct audits to determine who had access to the health records and what changes were made. Consent management is ensured and secured through the various participating organization on a blockchain [251], [252].

In a non-clinical setting, medical kits and devices can help patients undertake self-diagnosis. The lack of transparency and provenance about medical kits in existing systems makes it difficult for the patients to obtain reliable devices [253]. In this case, distributed ledger can be utilized to record data relating to performance, and reputation scores of medical devices in an immutable and transparent manner. As a result, patients may find it beneficial to obtain accurate and dependable medical kits from reputable manufacturers.

Third-party services are frequently used in today's health care systems to settle payments between patients, caregivers, and insurance companies for health care services. However, this method is expensive, slow, and does not handle micropayments. Blockchain platforms offer cryptocurrency tokens that can be used for payments. This direct transfer of tokens to the service provider's is a rapid, safe, and auditable mechanism that eliminates the need for any mediation service to resolve the payment disputes [254].

K. AUGMENTED AND VIRTUAL REALITY

Telemedicine has been proposed to solve the challenge of shortage of competent and specialized healthcare providers in many countries. It could provide health care services over both large and small distances. These systems are adequate for one-on-one communication between a doctor and a patient, or even a group of doctors, but may be unsuitable for chaotic situations such as emergency room [255]. Intrinsic advantages of augmented reality (AR) and virtual reality (VR) systems can overcome the challenges occurred during remote consultation and enables the ability to offer remote real-time instruction or expert assistance by projecting live annotations into the AR display of another operator. [255], [256].

Moreover, many studies have shown that AR and VR focus on improving physical, psychological and social well-being and aiding in everyday life tasks of older adults [257]. The COVID-19 pandemic has emphasized more the potential of digital technologies in general and VR in particular to support social contact, interactive games and physical activities with VR-integrated exercise, and tele-consultations with doctors during stay-at-home mandates [257]. Older adults, in fact, prefer to stay at home independently and feel comfortable in their familiar environments. At home, they perform various activities that are required to improve their quality of life and well-being. Due to physical and cognitive weaknesses, they need help to perform their daily activities. Similarly, there are many VR and AR interventions that assist the care givers to help elderly with dementia to improve their quality of life (QoL) in the care homes and also in their own home environment.

AR combines real and virtual content in a real environment on a real-time basis. AR displays are needed for viewing the merged virtual and real environment and they are classified into three categories: head-worn displays, see-through handheld displays, and projection-based displays. Among these displays projection-based displays are more suitable to the elderly in a home environment as the user is not required to wear or carry anything, and it can cover large surfaces for a wide field of view [258]. Although, they need a physical surface to project the content on. As elderly performs various ADL's such as cooking, bathing, medication, physical exercise, etc., at home and outdoors that are needed to improve their well-being and QOL. Each of these activities consists of many steps and elderly needs help to complete these activities. Various assistive systems have been developed using projection based AR to help elderly daily such as in a kitchen. Ikeda *et al.* [259] and Uranishi et al [260] have developed assistive system for elderly using projection technology to help elderly in a kitchen environment by projecting visual prompts at a kitchen top. Similarly, authors in [261] designed and developed a system by combining RFID technology along with the projection technology that can assist elderly in a kitchen environment to find objects from hidden places such as kitchen cabinets. A medication management system called MED-AR by Guerrero et al [262] that uses projection based AR technology for tracking and distributing prescribed medicines to the elderly in their homes. In all these systems, a remote caregiver is always available at a remote site that can guide the elderly using an audio and video connection. A system known as Memory palace has been developed by combining AR and Bluetooth beacons that replays memories associated to an object. This system involves the caregiver to the creation of the object memories and useful for the elderly as an aid to relive a particular memory [263]

VR, on the other hand, offers three dimensional (3D) dynamically rich multimedia content into a simulated environment that users experience by wearing a VR headset. Systems such as Virtual Forest [264], a semi-immersive environment, has been evaluated in the care home settings that projects images of the virtual forest on a large screen and small-scale evaluation suggested that this system can provide entertainment and can enhance mood. Physical exercises improve physical capabilities (e.g., enhanced motor ability, reduced obesity), cognition and psychological outcomes. In the editorial, Gao et al [265] explored the efficacy and effectiveness of various VR exercises among older adults over the age of 65 and targeted four most common poor health conditions seen in older adults. These conditions are decreased motor ability, increased obesity, impaired cognition, and psychological disorders, which lead to a lower quality of life.

VR and gaming technologies have the potential to assist elderly with disability in their day-to-day activities by enhancing the sensorimotor and cognitive functions. Exergaming, allows the introduction of different cognitive tasks to be performed concurrently along with the physical exercises. It is enabled by the use of VR to allow for the creation of ecological and controlled environments to allows user to perform stepping movements, weight-shifting, reaching movements, and/or aerobic exercises. [266]. Huang et al investigated the effectiveness of exergaming among the older adults. Their results indicated that the effects of immersive VR exergaming on selected executive functions (i.e., inhibition and task switching) contributed to more improvement in cognitive tasks than the non-immersive condition, situating immersive VR as a promising technology for preventing cognitive decline in older adults [267]. In addition, another study developed and tested a 3-D video game (NeuroRacer) [268]. Their results revealed that playing the game resulted in sustained attention and working memory and preservation of multitasking improvement in a period of six months [268].

Lin et al [269] designed a VR program called Rendever for older adults that uses network technology which allows group of residents to experience the same content simultaneously–enabling group travel, co-viewing of virtual photos and videos, and other experiences. This VR platform also allows older adults to speak with each other remotely in the virtual world even if they are geographically separated. The authors tested it with elderly people without cognitive impairment and results showed that the technology improved mood, energy, emotional and social well-being, and physical health [269]. Furthermore, Afifi *et al.* [270] used the same platform and tested it with MCI and mild-to-moderate dementia. Their results demonstrated that the network technology and long distance features work effectively, and both residents and family members were happy with the engaging VR experiences.

L. ROBOTICS

Robots are becoming increasingly sophisticated at performing what humans do, but in a more efficient, faster, and cost-effective manner. They have the potential to transform health care by allowing patients to stay independent, decreasing the need for hospitalization and care facilities. From surgical robots [271] to robots that assist the disabled and cognitively challenged [272], to robots used for telemedicine [273], there are many different sorts of health care robots. The use of robots may help to reduce the pressure on hospitals and healthcare facilities. Robots have been designed to assist the elderly in being self-sufficient and safe when they are alone. Robotics, as a field, has focused on many health care products including mobility aid, such as smart wheelchairs, artificial limbs, and exoskeletons [274], for example.

Social robots have a lot of potential in health care, since they can help people for long periods of time. People can leverage socially assistive robots to educate, motivate, enable communication, assess performance, and give social support [275]. Studies focusing on elderly care have discovered that social robots are frequently seen as non-judgmental and patient, reducing stress and encouraging openness [276]. Social robots have the potential to help health care providers in a way that saves money while simultaneously providing a very enjoyable and individualized patient experience [277]. One such example of a social robot is Paro [278], which was created with therapeutic aims in mind. Paro robots were put in the living rooms of an elderly care home so residents could engage with them. After one month, the results showed that Paro enhanced social relationships among the inhabitants of the care home. It was also discovered that after interacting with the robot, the residents' stress levels were decreased.

Robots can also assist elderly people in communicating with medical professionals and monitoring their health. They can, for example, be used to take vital signs and send the results to a doctor. These robots also have telecommunication capabilities, allowing them to provide consultations via video phone. Video conferencing is a low-cost method of providing better medical care to people who need to monitor their health and consult the doctors [279]. Patients can sit in their own homes while health care experts conduct routine and thorough medical screening procedures from their offices using video conferencing technology. Cafero [280], is a robot that can monitor a patient's health and allow them to speak with their doctor and obtain required documents. Hobbit [281] represents another care robot system designed for older adults, which focuses on detection and prevention of potential falls, as well as the proper handling of emergencies. It consists of a robotic platform equipped with five robotic arms and a gripper that can grasp objects of various shapes and structures.

Exoskeleton robots are a type of service robot that mimics, augments, or enhances the movements of the human body. The primary application for exoskeleton robots is in the medical field, where they are used to train muscular movements and aid in damage recovery. Exoskeleton robots, which have a similar kinematic structure to a human limb, are designed to be worn by the patient and provide essential support for the motion. These robots can also precisely measure data to assess the patient's condition. They have the potential to provide intensive rehabilitation on a consistent basis for a longer period of time. Exoskeletons may be able to treat patients without the presence of a therapist, allowing for more frequent treatment and potentially lower costs. The use of specially designed virtual games in conjunction with an exoskeleton can give a more enjoyable therapy experience, encouraging patients to put forth more effort [282]. There are some commercially available exoskeleton robots, one such example is The Lokomat, a stationary robotic system developed to support and automate treadmill training [283].

M. SECURITY AND PRIVACY

Security and privacy challenges come hand-in-hand with the creation of digital data and exacerbates with Internet connectivity. Huge amounts of data is created and shared with other systems in remote healthcare, thus, making security and privacy highly important. Furthermore, different types of technologies ranging from mIoT and WBANs to EHR and 5G are integrated together in healthcare systems making it a highly complicated environment. On top of that, all of these technologies have security challenges and distinct security solutions. Integrating such technologies further complicate the security and privacy landscapes. Therefore, below we discuss the most important security and privacy concerns and highlight potential solutions for those concerns.

1) SECURITY

Security of the whole ecosystem including the care receiver, care giver, remote assistants and doctors, the systems used by receivers and providers, as well as the underlying communication and computation infrastructure enabling the ecosystem is of paramount importance. Albeit the benefits of online and connected systems, there are serious security concerns attached to such systems. For example, the 5G systems do have security challenges, as elaborated in [201], [202], and thus there are research efforts directed to the security of health care in general and remote health care in particular.

A four-dimensional zero-trust security system that provides situational awareness and protection for 5G-based smart medical platforms is proposed and evaluated in [203]. The work first categorizes the main threats against smart health care systems into i) large-scale monitoring and theft of medical data and patient privacy information, ii) attacks on critical infrastructure, and iii) malicious data tempering of medical records. The system builds dynamic and fine-grained access control, provides real-time network security situational awareness, and continuous identity authentication and analysis of access behaviour. By using MEC, the system performs identity verification, access control, authorization of IoT devices and monitoring its behavior at run-time, and detecting fake or illegal connections.

Since cloud systems are entering into all fields of IT systems, securing the information and medical records of individuals through identity-based cryptographic techniques in cloud systems have been demonstrated in [284]. Identity based encryption and identity based proxy re-encryption techniques can overcome the challenges of saving and using complex keying techniques in public key infrastructure (PKI) techniques [284]. Simplicity and ease of use in security techniques are the most important aspects, since most security procedures are avoided mainly due to complexity [285]. A cloud-centric authentication scheme for wearable devices is proposed in [286]. The article [286] elaborates how wearable devices, comprised of a variety of sensors, and used in monitoring in remote health care along with its communication, can be secured through secure mutual authentication.

Remote health care is highly dependent on wearable technologies, mostly comprising tiny sensors implanted in body, smart watches, or other IoMT devices. These devices have low resource in terms of memory, processing, and power. Therefore, security of medical health care devices with low resources (e.g., storage and computing) will be among the major concerns due to the fact that most strong security techniques require higher resources. For example, a comprehensive study on the security of IoT devices is carried out in [287]. The authors conclude that very limited number of IoT devices, the applications and communication protocols have been assessed from the security point of view, and have generally a number of security vulnerabilities. Similarly, machine learning has been proposed to be used in communication networks in general [288] and IoT in particular. However, machine learning will bring its own security challenges as discussed in [289]. In IoT the use of machine learning can be further challenging, as discussed in [290]. The use of IoT in remote home care will require further deliberation in terms of security. The potential solutions include security-by-design of IoT devices, its interfaces, and communication protocols. Furthermore, the communication security aspects can be addressed by ensuring the security of the communication infrastructure through proper security service-level agreements (SLAs) with the service providers to ensure network-wide end-to-end security. Furthermore, security by isolation is another approach, where the traffic of remote health applications and services can be differentiated from others [198]. However, this is an emerging research area and need further research to investigate the possible challenges and potentials solutions to such challenges.

2) PRIVACY

Data privacy protection in the health care domain is among one of the forefront concerns. The modern digitization in remote health care have provided several advantages at one hand, but, on the other hand, it makes the protection of data privacy much more complex. For example, using remote video monitoring at home (elderly or disabled persons), the patients' or users' daily life activities may also be noticed by unauthorized persons, and which may later be used for harmful purposes. In centralized cloud-based remote health care, the gathered data of patient is either sent to the assigned medical server or to the cloud for further processing, analysis and storage purposes. The further the raw data (e.g. video feed from home) needs to be sent, the greater are the risks for data leaks. Furthermore, integrity and reliability of digital health care records is needed by the doctors and health care staff to ensure the better diagnosis and treatment [291], since unauthorized alteration or manipulation in these digital records may cause result into poor/inaccurate diagnosis.

Furthermore, in the hospital premises, the medical records might be accessed by several health care personals (doctors, nursing staff, laboratories) even if they do not have any direct link with that patient [292]. Therefore, it is highly important to define secure data access mechanisms, i.e., who is and who is not authorized to access the information based on their job roles. Collection of patient data is highly important in remote health care and has many faces of security challenges ranging from threats within the communication media to storage and processing of the data [291]. The patient data should be verified to ensure integrity of medical records and other important user data. Distributed ledger and blockchain techniques, as discussed in subsection V-J, can play an important role in secure access to such data and medical records.

Patients should be capable of anonymously authenticating themselves (Ref) to update their data on the data servers. Anonymous authentication should be secure and the anonymity should be verifiable and revocable by the relevant responsible authorities. In a literature review on sensor-based authentication systems in remote health care, authors in [293] deliberate on the weaknesses of authentication through mobile phones. To avoid complexity, elderly persons may also avoid using strong authentication systems. Hence, security authentication techniques where active involvement of user is minimized, for instance, through using biological features such as gait, face and voice recognition, etc., as evaluated in [96] will be more secure.

Recently, advanced mobile gadgets and wearable devices have been taken into use to measure the vital health signs remotely at home, from office or during any outdoor activity. These gadgets (wearables) use mobile applications (mobile apps) e.g., Android or IOS for various services/features during the monitoring [294]. There is a high possibility that hackers target these applications and leak the private data of the user. Moreover, the app developer can share the health related data to the third-parties or interested stakeholders (for building new apps/products) without the consent of the user. Thus, data transparency concerns are raised and consumers do not have complete trust on such health care mobile apps.

The modern health care IoT systems consist of various involved stakeholders, such as medical experts, hospital administration, laboratories, infrastructure providers, etc., providing different medical services. The patients' health care data is confidential and highly sensitive, and therefore compromising the privacy can cause a significant negative impact on patients and the overall health care system. The patient's privacy can mainly be targeted from three perspectives; i.e. data, location and identity (Liyanage *et al.*, 2018). Therefore, efficient and privacy preserving solutions must be used to ensure the privacy of the overall communication of involved entities. For example, edge-based privacy preserving solutions will be vital to limit the propagation of sensitive health care information near to the data source (Li *et al.*, 2019). In addition, the approaches such as privacy-by-design, data miniaturization, accountability and transparency need to be considered while designing the privacy for future digital systems (Kumar *et al.*, 2017).

VI. FUTURE RESEARCH DIRECTIONS

Even though great developments have happened and achievements have been made in the realm of remote health care, there still exist important issues that require further research. In this section, we discuss the most important research challenges that exist in those technologies and technological paradigms that are elaborated throughout the article. The most important research challenges are also framed in the form of research questions in Table 10 along with possible research directions. These challenges and research directions are briefly discussed below.

A. REMOTE MONITORING AND AID

Remote monitoring and aid are among the most essential remote health care services. Considering the current COVID-19 pandemic situations and the foreseen post-pandemic era, it is highly expected that several advanced remote health care services and challenges will emerge [295]. The role of AI will be immense in the next generation remote health care systems for automating different processes, e.g., automatic monitoring, diagnosis and corresponding recommendation for the treatments [296]. Furthermore, the integration of various enabling technologies into the remote health care systems would likely to make communication networks much more complex, and hence future research is required in this direction as well. Data privacy and trust management mechanisms are the forefront requirements for the adoption of future telemedicine systems and hence, appropriate solutions must be placed from various aspects, i.e., technical, legal and ethical. A great amount of research and efforts will be needed for making standardized telemedicine systems and solutions which should be acceptable to all the involved entities/stakeholders (specially the user) and well-aligned according to the privacy guidelines defined, such as in the GDPR by Europe, and in HIPAA Privacy Rules by the United States.

B. AMBIENT ASSISTED LIVING

The design approaches of the future AAL environments should be user-centric, meaning that users' inputs must be taken throughout different design phases. In addition to this, future research is required for building adaptive AAL systems that can respond to the dynamic changes in the needs of users, and their behavior and habits over time [297]. Some of the enabling technologies such as AR/VR, assisted robots, etc., aimed to enable advanced AAL environments are still in very early phases and thus require further research to exploit their full potential. Since the aging population will increase significantly in the near future and they may have limitation in terms of physical activities, and lack technological awareness, further research is needed in developing age-appropriate user interfaces. Furthermore, research is needed to explore various interaction approaches for friendly user access interfaces that provide natural or seamless access to digital services to different age groups who need remote health care services [97].

C. ELECTRONIC HEALTH RECORD

As EHR systems are mainly built to integrate and display institutional and already categorized health data, there is a major challenge to integrate remote care data originating from diverse sources into these platforms. There are needs for both technological breakthroughs and disciplined implementations of regulatory frameworks and standards. The future research should make use of latest innovations to present data in a timely manner over secure 5G / 6G networks, and at the same time finding the intelligent AI and Edge computing solutions for processing and filtering the most relevant data. With heterogeneous source systems, it is essential to perform user experience studies among health professionals for best practices in data display and manipulation. Additional studies are needed to assess the role of patient generated data [298] and the role of citizens' personal health records in the treatment chain [299]. The final value for remote care systems for healthcare service system is evaluated on impact analysis studies [300], where effortless access to relevant health data through the EHR platform plays an important role [301].

D. BIG DATA MANAGEMENT AND ANALYTICS

Big data analytics acts as the backbone to any healthcare organization, as it provides the facility of effective data storage and generation of insightful analysis. There are a number of benefits that big data analytics can provide to healthcare that can also be further investigated which include; i) disease prediction and detection at the initial stage, ii) quick and efficient management of every individual's health for better monitoring and addressing frauds in health care, iii) cost-effectiveness and building efficiency across all healthcare sectors, and iv) generating new insights into the spread of disease and understanding their mechanisms. The existing big data approaches are still in their infancy when it comes to addressing data integration and management challenges. Enabling access to diverse datasets will help in more thorough analyses related to patient outcomes and support improved decision-making for healthcare systems. To achieve the full potential of big data systems, there is a big need to investigate and improve the data integration and scalability mechanisms for big data systems and addressing the real-time analysis and privacy challenges at the same time. For this, a promising

TABLE 10. Summary of important research questions and directions in remote health care.

Technologies	Research question(s)	Research directions
Remote Monitoring and aid	How to enable autonomous and dynamic advanced remote monitoring systems that can provide the needed healthcare services and take care of security and data privacy?	Build intelligent remote monitoring systems by combining emerging enabling technologies and devices/sensors with the future network and communication architectures. These systems must also provide distributed trust and privacy protection mechanisms.
Ambient Assisted Living	How the advanced AAL environment can enable intelligent, dynamic and secure healthcare solutions to the target users in both indoor and outdoor environments?	To develop the future AAL environments, the research is required in various key domains, i.e. supporting technologies, interaction modalities, energy and cost-efficient devices/sensors, data analytics mechanism and ensuring security and privacy.
Electronic Health Record	How to integrate the data coming from remote care systems to the existing EHR platform? How to tackle data privacy and confidentiality issues and semantic interoperabilty of the data content arriving from diverse subsystems? How to extract useful information and how to prevent data overload?	Build data transmission chains based on existing regulatory framework and conforming with present standards in EHR environment. Design novel user interfaces with easy-to-use tools for professionals and based on research results in user experience studies. Create intelligent background algorithms for processing of displayed data.
Big Data Analytics	How can open access to diverse healthcare big data sets and their analysis improve decision-making? What types of data processing and storage technologies best facilitate high performance and efficient data processing of data-intensive medical services in distributed remote health care?	A number of challenges such as the heterogeneous nature of datasets and their formats, data integration, scalability, real-time analysis, and privacy concerns are associated with big data management in healthcare systems which need to be further investigated. Utilization of event streaming technologies that allow processing data streams with high throughput and low-latency and that are interoperable with DLT technologies.
Distributed Service Architectures	How to effectively utilize distributed service architectures and edge intelligence to optimize e2e performance, efficiency and fault-tolerance for real-time mission-critical healthcare services? How to ensure the correctness of the operation and trustworthiness of service components in distributed service architectures to ensure the data management meets the high privacy requirements of healthcare services?	Develop AI-based methods to dynamically optimize the placement of computational tasks and data flow in the edge-could service architecture to ensure timely processing of data while avoiding overload on different system components. Utilize DLT technologies for detecting misbehaving system components and to build trust among the different stakeholders of highly distributed healthcare service architectures.
AI and Machine Learning	How to build an AI model that can fit and predict complex chronic diseases based on full-cycle data?	Chronic diseases are highly hidden and sustainable, which are hard to predict. AI and machine learning are important methods for extracting hidden lesion features from data and discovering unknown mutations, requiring further research. Constructing in-vivo and in-vitro multi-dimensional data collection and collaborative analysis models may help predict chronic diseases.
5G	Are the unique requirements of remote health care already fulfilled by communication technologies? Will the integration of diverse equipment and services expose patients to new challenges, such as security?	Gathering the unique requirements of different equipment in the healthcare sector and developing KPIs for them accordingly are still lacking. Secure integration of different medical equipment and services, and adopting the principle of security-by-design needs further investigation.
IoMT	Which IoMT devices and technologies are required for supporting remote health care and assisted living? How to balance the efficiency (e.g., cost, energy and resource), dependability and user acceptability of IoMT systems? How to approach implantable IoMT?	Integration of the different IoMT devices and technologies into a single ecosystem. Extensive use of remote sensing technologies on the one hand, and more advanced wearable and even implant IoMT devices.
Location technologies	What kind of solutions are needed to support seamless positioning indoors and outdoors? Can we use same technologies to locate people and things?	Integration of satellite and terrestrial based radio technologies and development of a navigation service using history data could assist elderly in everyday activities. However this requires more investigation e.g. in order to prevent spoofing.
DLTs	How blockchain platforms can be made scalable and cost-effective, to provide hundreds of thousands of transactions without long confirmation times and high fees? How to speed up the adaption of blockchain in health care in general and remote health care in particular? How to make blockchain platforms interoperable with other platforms and integrate with legacy systems?	Develop new blockchain architectures and new consensus algorithms specifically designed to tackle scalability problem. There is a need to develop standards for the widespread adoption of blockchain technologies. Further research is needed interoperability, security, fault tolerance mainly for healthcare applications.
AR/VR	How to design AR and VR systems that can work in remote locations with poor or, sometimes, no high bandwidth connectivity.	Leveraging AI and machine learning to understand user needs locally, using edge and fog computing to store systems and services locally to provide guidance without high bandwidth connectivity, and developing low-bit rate AR and VR technologies, are the key areas to address the issues.
Robotics	How to design robots for long term interaction? How to design robots for remote health care that can support its unique requirements? Are there security and privacy issues in social robots, and ethical implications of interacting with robots for extended periods of time?	Robots need to be extensively trialled in the homes to find it out their effects and implications. More research is needed on robots specifically designed for remote health care and that their security and privacy should be according to the established and required standards.
Security and Privacy	What can be the effects on security and how security can be preserved in the NextGen health care?	There can be diverse security challenges. Isolation through slicing and virtualization in the network and cloud environments present interesting research directions.
	How to ensure the data privacy protection for user's sensitive healthcare information?	Further study and research is needed on privacy enhanced technologies to develop the needed privacy solutions.

avenue for future research include utilization of event streaming technologies that allow processing data streams with high throughput and low-latency and that are interoperable with DLT technologies that can provide sufficient level of trustworthiness in distributed mission-critical and data-intensive healthcare applications.

E. DISTRIBUTED SERVICE ARCHITECTURES

As we stated in Section VE, serverless edge computing utilizing the available local computational resources enables various functions to be deployed locally, which has potential to improve e.g. data privacy and more efficient use of ICT resources. According to our studies, lightweight nanoservices can be deployed on available local IoT devices without compromising the performance of the services [302], [303]. The growing demand of heterogeneous IoT services at smart health care systems requires solutions dynamic service provisioning [304], which, furthermore, requires addressing the following questions: 1) how relevant services can be discovered from a service repository and deployed dynamically into heterogeneous IoT node in accordance with the service requirements and the available capability of the local nodes in terms of a node's CPU, RAM, storage, sensors and actuators, etc.; and 2) how to use different optimization algorithms and models to optimally leverage the underlying computational, sensing and actuation capability to e.g. maximize the health care data management performance, reliability and security, while ensuring sufficient system-level resource and energy-efficiency.

We have started the work of addressing these issues in [305] and [306], and the work continues. Furthermore, Intelligent AI-based collaboration between the edge-cloud architecture and the underlying network architectures can bring more intelligence to medical applications. As an example, in terms of privacy, the management of sensitive patient monitoring data can be secured. In most cases, privacy-sensitive data can either be processed locally or anonymized locally to enhance the security against privacy attacks. Similarly, the privacy of machine learning can be brought to a new level, since local training reduces the need for sending sensitive training data to centralized ML components.

F. ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Predicting chronic diseases in advance and informing patients and their families is one of the most important prospect of remote healthcare. However, the existing diagnosis of chronic diseases based on supervised learning requires a large amount of sample data [307]. The diagnostic effect of AI models is limited by the quality of data annotation, and this type of research ignores the continuity of stroke management and fails to capture different gestures and strokes [308]. There is a lack of information for implicit relationship of evolution. Therefore, how to build an AI model that can fit and predict complex chronic diseases based on full-cycle data will be one of the key development directions in the future. To address this problem, it is necessary to further integrate AI models such as semi-supervised learning, multi-modal learning, graph neural network, etc., so as to extract hidden pathological features from massive data, and build in vivo and in vitro multi-dimensional data collection and collaborative analysis models. The main aim is to help predict chronic diseases.

G. 5G AND BEYOND

5G has been standardized for the most part and has been actively deployed. Zero touch deployment of medical service, fully automated and intelligent health care services that can follow users from one environment (e.g., indoors) to another (e.g., outdoors) can be envisioned in wireless networks beyond 5G. Since research on 6G has already started, its impact and what it offers in the domain of remote health care is yet to be seen, and needs dedicated investigations. 5G, for instance, cannot meet the latency requirement of a robotic arm when the robot is operated from more than 50 kilometers, since 5G can hardly attain an end-to-end delay of 1 millisecond [309]. However, performing remote surgery, for example, from a distance farther from 50 kilometers cannot be ruled out completely. However, 6G will bring new horizons into healthcare, as discussed in [310]. 6G will have the potential to make the human body a part of the net, leveraging on Bio-Nano-Things. Similarly, immersive applications needed for remote health care will require higher bandwidth and mobile broadband reliable low latency communication (MBRLLC), which is also envisioned in 6G [309]. The integration of satellite-based connectivity with terrestrial systems, already being part in the standardization activities, also needs further research in the domain of remote health care. Moreover, 5G has security challenges [201], [202] which are more concerning in remote health care due to its sensitive nature. Therefore, remote health care requires proper investigation of technologies and technological paradigms envisioned in 6G to safely and securely meet its unique requirements. Internet of Bio-Nano-Things, letting the human body be part of the "Net".

H. INTERNET OF MEDICAL THINGS

Likewise the conventional IoT, the IoMT is extremely diverse which makes this hard to identify the common trends and the most perspective directions of development. The novel wireless connectivity technologies, which are in development today, including the 6G, promise moving forward the communication performance (e.g., in terms of maximum throughput, range, latency and consumption) and thus enable the novel applications. The advances in electronics, computing and AI, and edge would enable making the individual IoMT devices and applications/services more smart and pervasive. However, the great heterogeneity of the different technologies creates a major challenge, which is: how to enable interconnectivity between the different devices/applications and, as ultimate goal, merge them into one single ecosystem? Notably, this has to be handled without compromising the application performance indicators (e.g., lifetime and quality of experience) while upkeeping high security and privacy.

To tackle this challenge, a higher level of flexibility is required at all levels. First, both the radio transceiver and the processing system of IoMT devices need to become more flexible and reconfigurable as well as more intelligent (through new algorithms, based, e.g., on AI/ML) to benefit and effectively exploit this flexibility. Second, there is an urgent need for developing uniform protocols, interfaces and message ontology to serve as a common language allowing the individual IoMT devices and applications stay aware of their environment and facilitate collaboration. Third, there is a need in developing the new ones and updating the existing regulations (e.g., the ones dealing with frequency spectrum) related to the use and certification of the IoMT devices, especially these which operate next or even inside a human body, to ensure their safety and ensure user acceptance. While the two former challenges will be partially approached by the 6G [311], the latter goes beyond the domain of technology.

I. LOCATION TECHNOLOGIES

Most of the localization techniques require that the person to be localized is carrying relevant technology. The solution to be used widely should be easy to implement, low cost and not requiring elderly to remember actively using it. This is one of the challenges whether the research looks for magnetic, optical or radio technologies or something else. It would be very useful if there would be an assisting system that can locate things inside house to help elderly to find them. A clear challenge for future development is accurate 3D positioning [312], [313] that 6G is aiming to offer.

Since use of positioning technologies for remote home care includes human-based studies and development, there is a risk of revealing and accessing personal data. Thus, ensuring privacy and taking care of ethical issues should be always prioritized in development activities. However, real-world scenarios are needed in technology development since environments can differ significantly from laboratory settings.

J. DISTRIBUTED LEDGER TECHNOLOGIES

The adoption of distributed ledger technologies in health care applications could revolutionize the health care sector. Research should be directed to redesign blockchain models in order to be more suitable for health care systems. The full potential of blockchain technologies in remote health care is hindered by the lack of awareness and maturity of blockchain technologies, as well as the lack of security and privacy standards. Hence, more research is needed on these themes [314]. Moreover, the adoption of blockchain in health care needs standardization and regulations of relevant technologies. The scalability of blockchain, that constitute a major research problem, is related to the metrics of throughput, latency, bootstrap time and cost per confirmed transaction [315]. Currently, the large amount of data is one of the major problems in terms of transaction fee and time. However, the solution of this challenge is a trade off between scalability and security.

While blockchain was designed to be a decentralized technology, individual blockchain networks are not naturally open and cannot communicate with one another adequately. Blockchain interoperability does not simply refer to the capacity for different blockchain systems to communicate with one another. It refers to the ability to share, and access data across many blockchain networks without the need for an intermediary. This challenge is significant because blockchain-based health care systems use various blockchain networks and platforms. However, architecting such interoperable blockchain platforms is difficult due to a variety of issues, such as differences in the blockchain platforms' supported languages and consensus protocols.

K. AUGMENTED AND VIRTUAL REALITY

Various AR and VR-based systems have been developed for remote health care, specifically for older adults to promote their well-being, improve QoL and enhance autonomy in the performance of activities of daily living. The results of using these tools show significant improvements. However, there are few considerations that are important for future work. The most important consideration, usually overlooked, is the involvement of patients or care receiver such as older adults in the design of AR and VR systems. Similarly, individualized and specially designed interactive VR applications are needed to avoid negative social withdrawal, addictive behaviors, and issues surrounding one-to-one supervision by care staff [316]. Moreover, central to the use of AR and VR in remote health care is the availability of communication infrastructure and the availability of high-bandwidth connectivity. This represent two dimensions in future research. One, systems that can be used without active connection, for instance, using localized storage for important working data that can deliver some level of guidance that is commonly provided through AR and VR systems. Secondly, AR and VR systems that can work on low bandwidth connections for remote health care. These two represent major future research directions that are not investigated well in this domain.

L. ROBOTICS

Robots have a great potential to help in remote health care from many aspects, including relieving burden from health care professionals and helping the care receivers. However, healthcare robots are still in the research phase. Commercially available healthcare robots are expensive, and the cost does not allow the ubiquitous use of robots. This is the main reason for the rare deployment of robots in real work environments [317]. Therefore, developing less costly robots constitute one of the most important research directions. There are also many obstacles for the adoption of robots in the field of remote health care, and the most important one is the reluctance in acceptance for help and aid. This can also be a result of the lack of maturity and readiness of the technologies of robotics, which needs studying the aspects of technology acceptance techniques. In order to ensure the seamless integration of robots in healthcare, it is important to ensure their reliability and performance.

M. SECURITY AND PRIVACY

There are no standardized approaches to measure the effectiveness of zero-trust architectures, specifically in the health care sector. This puts the security of remote health care units or smart facilities in further quest for research investigation. The existing proposals have difficulties in technical implementation and in creating public awareness regarding its need, importance, and use. Furthermore, standardization activities in terms of security of IoT devices and communication protocols is slower compared to emerging threats. A holistic security-by-design approach from the manufacturing to the deployment and maintenance phases should be followed, which is currently lacking. In terms of privacy, most of the emerging technologies have no privacy related standards or, for that matter, specifications. For example, the use of AI and machine learning requires gathering raw data, which in this case is patients' data. Such data is highly sensitive, yet most of the technical development on the side of AI and machine learning do not give it the required consideration. Hence, privacy of data and user information in technologies used by remote health care needs further investigation to not only expose those technologies that can exploit user privacy, but also propose privacy preserving techniques for essential technologies.

VII. CONCLUSION

Remote health care has been an important part of the health care ecosystem from the past few decades. However, the recent COVID-19 pandemic has re-invigorated research in this domain and brought it to the forefront as an important pillar for the smooth and secure functioning of our societies. Therefore, in this article we deliberate to explain the important technological paradigms and enablers of remote health care systems. In doing so, first the main compelling reasons for the use remote health care are discussed as part of remote monitoring and remote aid. Second, all the important technological constituents are identified that play vital role in fulfilling the needs of remote monitoring and remote aid. Third, each of the identified technologies and technological paradigms are discussed through state-of-the-art studies. The existing technologies, emerging technological concepts, and research efforts explained. Fourth, important research gaps are identified to stir future research in each technology within the umbrella of remote health care systems. In summary, this article sheds light on existing and emerging technologies for remote health care along with important future research directions with the aim to improve the well-being of our societies.

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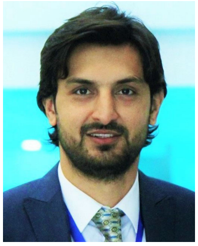

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