Digital Health, Big Data and Connectivity: 5G and Beyond for Patient-Centred Care

REVIEW ARTICLE

ANTONIO FRANCHI
LUCA FRANCHI
THOMAS FRANCHI

*Author affiliations can be found in the back matter of this article

IJS Press
Part of the IJS Publishing Group

ABSTRACT

This paper presents a vision for the future of the digital healthcare sector. It illustrates the emergence of new use cases where the care and safeguard of patients is enhanced, thanks to the advancement of breakthrough technologies which are revolutionising healthcare. In particular, the realisation of the 5G connectivity telecommunications standards and its worldwide adoption is identified as one of the principal enablers for the digital health revolution. Delivering on the 5G promise of making connectivity ubiquitous and secure will open incredible opportunities for the health sector, creating a booming digital health economy. This will ultimately provide superior healthcare via universal, digital, and responsive services. Here, we provide a broad review of 5G in digital health for readers interested in the field.

CORRESPONDING AUTHOR:
Mr Thomas Franchi, MSc FHEA MAcadMEd
The Medical School, The University of Sheffield, Beech Hill Road, Sheffield, S10 2RX, United Kingdom
tpffranchi1@sheffield.ac.uk

KEYWORDS:
5G telecommunications; digital health; telehealth; connectivity; autonomous systems; big data; artificial intelligence; machine learning; augmented reality; virtual reality; internet of medical things; satellite

TO CITE THIS ARTICLE:
Franchi A, Franchi L, Franchi T. Digital Health, Big Data and Connectivity: 5G and Beyond for Patient-Centred Care. *International Journal of Digital Health*. 2021; 1(1): 1, 1–10. DOI: *https://doi.org/10.29337/ijdh.24*

1. INTRODUCTION

A new era of digitalisation and connectivity, between everything and everyone, has the potential to change the fundamentals of human existence: the way we interact, produce, live and work. Driven primarily by technological forces that support new connectivity, computing and consuming paradigms, this fast-approaching socioeconomic transformation will cause changes to human behaviour, but also massive disruption to business models. Traditional industry sectors which are not yet digitalised and remain relatively unevolved are now embracing the incoming digital transformation. Indeed, the medical sector is embracing the transition towards digital health [1]. 5G technology will supply the connectivity needed to support this transformation [2], enabling new applications and services, arising alongside novel value propositions in the "5G world" [3]. In this paper, we aim to provide a review of 5G in digital health and to present a vision for the future of the digital healthcare sector.

2. CONNECTIVITY AND THE FUTURE OF HEALTHCARE

5G is the fifth generation of cellular wireless technology. Its potential to transform how healthcare is delivered is vast, thanks to its ability to provide high speeds, support many connected devices and offer ultra-reliable and low latency connectivity (***Figure 1***) [4]. Once fully deployed, its ubiquity will alleviate current inequalities in healthcare provision due to imbalanced distribution of resources [5]. 5G has the capacity to both impact and enable medical innovation in several areas, including the Internet of Medical Things (IoMT), augmented reality (AR), virtual reality (VR), artificial intelligence (AI), remote medical learning and remote patient monitoring. The core features, and associated challenges, of 5G are summarised below:

1. **Bandwidth:** 5G promises to provide very high capacity for each individual user. This results in an unprecedented bandwidth requirement imposed on 5G networks. Careful network planning will be required to be able to satisfy different users and use cases over the same 5G network.
2. **Massive Number of Connected Devices:** 5G is designed to accommodate the myriad of connected devices forming the IoT [7].
3. **Mobility:** As different users and use cases will rely on connectivity everywhere, 5G will have to accommodate a wide range of mobility use cases and provide the security and continuity required, whether the user is at sea, on land or in the air for moving platforms, aircraft, ships and trains.
4. **Broadcast (Simultaneity):** Some use cases will require the broadcasting of the same information

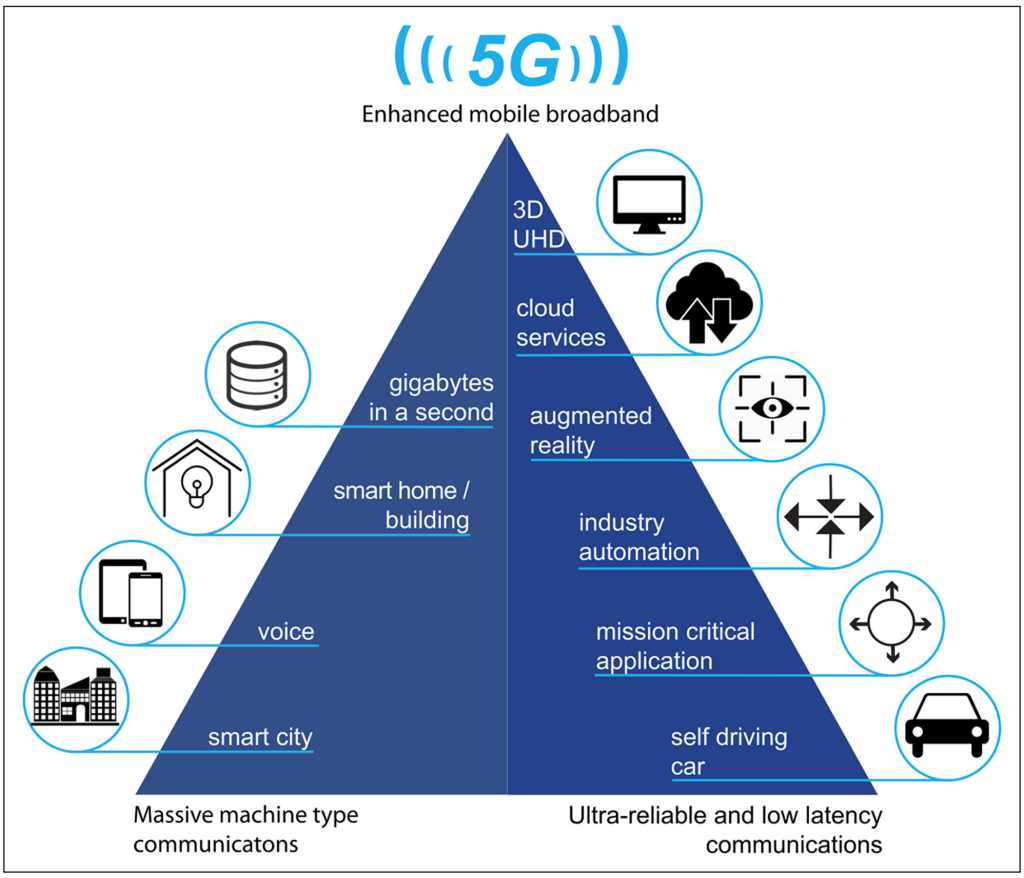

Figure 1 Benefits of 5G to the healthcare industry. (Image credited to the University of Oulu [4]).

to a variety of geographically dispersed users. Optimising content delivery for these cases is important to minimise strain on network recourses. Satellites can efficiently deliver rich multimedia content across multiple sites simultaneously, using broadcast/multicast streams with an information centric network and content caching for local distribution.

5. **Security:** Preventing improper access to data (hacking) is instrumental to the widespread adoption of 5G, which promises to guarantee end-to-end security and integrity. This attribute of 5G is particularly pertinent in the provision of digital healthcare which involves vast amounts of private patient data.
6. **Reactiveness (Low Latency):** Some of the 5G use cases (such as haptic and tactile internet enabled telesurgery) demand very high reactiveness and low latency. The 5G network will have to implement mechanisms to minimise network delay and distribute information at the edge of the network predictively to optimise the network response time.
7. **Ubiquity:** Public perception and demand dictate that 5G will be available in city centres as well as the rural and remote areas of the world [6]. This is challenging, given the relatively low coverage range of individual 5G base-stations and the slow deployments of terrestrial 5G networks, which will inevitably prioritise city centres, rather than rural areas. For ubiquity to be realised, satellite telecommunication networks will be needed to complement 5G terrestrial coverage, providing high-speed capacity across the globe.

In order to deliver on the above promises, 5G networks will operate seamlessly, across a set of heterogeneous network elements, with satellites playing a critical role in this evolution. Network convergence is the key to a future in which we will see new players emerging, such as Virtual Network Operators, pooling terrestrial and satellite services in different domains and use cases. Innovation and novel service development, benefiting from an integrated satellite and terrestrial service, will be required in each service domain.

3. HEALTHCARE USE CASES AND 5G

The future of healthcare will likely be driven by digital transformation enabled by radically interoperable data and open, secure platforms (***Figure 2***) [8, 9]. Further, health is likely to revolve around sustaining well-being rather than simply responding to illness. Four concentric layers surrounding the patient have been suggested as a model for the future of healthcare, which describe the catalysts needed for change, the jobs which need to be done, the enablers, tasks and future business archetypes [8].

The next revolution in global healthcare will come hand-in-hand with the revolutionisation of global connectivity and interconnectivity. Together with most other aspects of society, healthcare is rapidly moving towards a decentralised system, making use of an exponentially increasing number of connected smart devices to achieve a more patient-centred care system [2]. Given the vastly expanding virtual environment associated with the healthcare sector, it stands to benefit from 5G and its associated advance technologies. The focus of the next development in healthcare will be on big data. Moving to a decentralised system will result in a huge increase in data and subsequent data handling and processing; the limitations of current network infrastructure will be overcome by the deployment of 5G networks. Previous authors have highlighted the

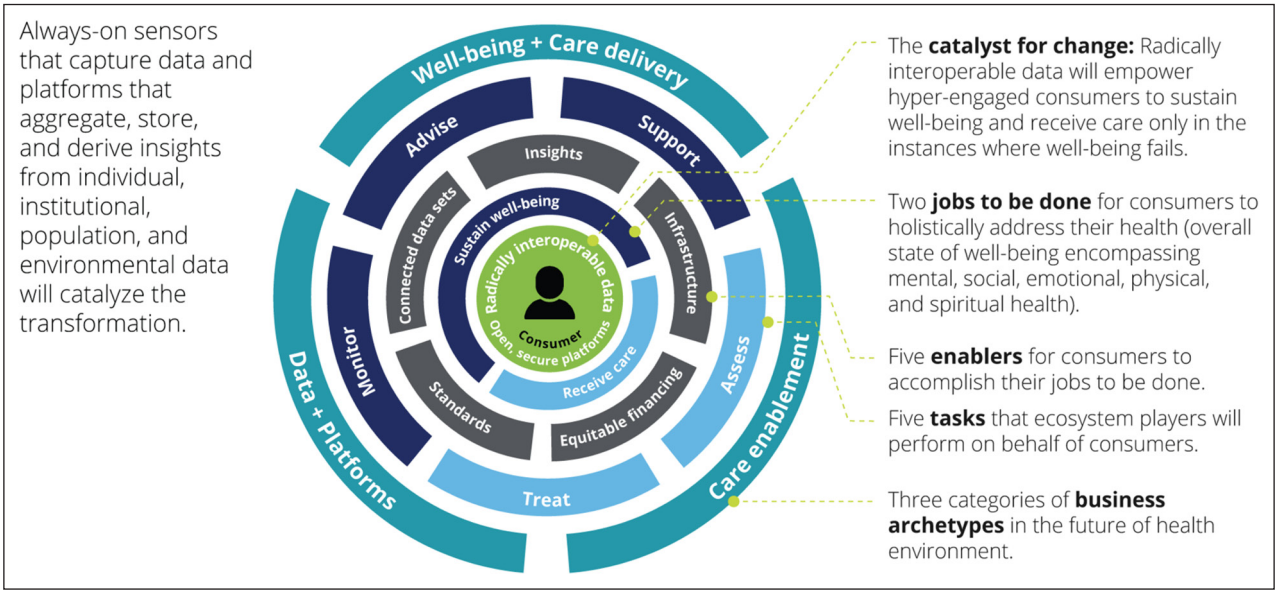

Figure 2 Digital transformation required to drive the future of health. (Image credited to Deloitte Insights [8]).

requirements and technologies trend of 5G-based healthcare [2, 7]. Select use cases of this technology, which are not exhaustive, are summarised here [2, 10]:

1. **Remote Patient Monitoring:** The industry of wearable technologies is growing rapidly and is being harnessed in the healthcare sector [11]. The future sees a wide-spread use of wearable and stationary devices, constantly monitoring facets of users' health. These connected devices can provide an accurate, real-time representation of a patient's health and lend medical professionals the opportunity to keep track of it consistently rather than intermittently. Increasing the abundance and connectivity of these devices, tying into the Internet of Things (IoT), will allow for continuous data analysis, quicker response times, improved insights and will reduce the need for mundane check-ups.
2. **Telehealth:** The Covid-19 pandemic has caused societies around the world to rethink aspects of daily life previously taken for granted; the healthcare system is no different [12]. During the last week of March 2020, the Centers for Disease Control and Prevention (CDC) documented a 154% increase in telehealth appointments [13]. This has allowed societies to fully realise the power of such a system and will bring about lasting change. So much can be achieved through video-enabled consultation; the far-reaching applications include elements of care from prescription management to routine diagnoses. In addition to seamless, high-quality video exchange, effective telehealth requires scrupulous security infrastructure; 5G will allow for a wide-spread adoption of this form of healthcare and will improve access to care when demanded [12].
3. **Big Data in Artificial Intelligence and Machine Learning:** By definition, 5G will enable a greater exchange of highly secure data at a much greater rate. This, in turn, will provide scope for revolution in data analysis in healthcare. Traditional healthcare systems often result in suboptimal health outcomes due to personal biases of clinicians and incomplete knowledge of the patients' health [14]. In order to achieve optimal results, healthcare systems must turn to statistically validated data and advanced learning algorithms. Given again the vastness of data to be handled and the importance of its security, 5G will play a pivotal role in the training of said AI and ML algorithms. A combination of intelligent monitoring devices, video and image processing, recognition and analysis algorithms and testing procedures as well as a clinician's expertise [9], will provide an enhancement in effectiveness comparable to diagnosis with, rather than without, internet aids. Indeed, deep learning is already used to detect skin cancers in images [15], and so 5G connectivity and beyond will result in a drastic improvement on these capabilities. In addition to image diagnosis, AI applications in healthcare are far-reaching and will transform aspects of the sector such as clinical trial participant identification, administrative workflow assistance and robot assisted surgery [14, 16]. Predictive analytics and big data, which can only be effectively achieved by 5G connectivity, will revolutionize diagnosis and treatment plans in healthcare [17].
4. **Connected Ambulances:** By harnessing the power of wearables, sensors and video streaming from ambulance to hospital, the doctors at the hospital have an enhanced understanding of the medical state of the patient prior to arrival; this incredibly powerful information will allow hospital staff to better prepare for incoming patients, hence increasing the effectiveness and efficiency of their treatment of said patients [18]. Such a feat can only be achieved with 5G connectivity thanks to its high bandwidth, security and reliability providing confidence in the streamed content.
5. **Virtual and Augmented Reality:** The sheer power that AR/VR technologies have is yet to be harnessed but as the technologies develop, the impact they will carry is becoming more evident. The low latency and high bandwidth that 5G offers will allow ultra-HD video to be utilised in VR headsets and provide reliability in the technology [19]. VR is used in a primitive form in training and education, but with the next generation of connectivity, the training of medical students, allowing them to practice procedures virtually and collaborate on said procedures in real time, will be greatly enhanced. Further, AR headsets, and subsequently lenses, will assist those with impaired vision to achieve everyday tasks which seem distant without technological aid. Connection to advisors, human or machine, will allow them greater liberties when walking outside and crossing the road, for example [20]. Again, these headsets must be 5G-enabled due to the requirement for near-zero latency video transmission and mobility. Headsets of this nature also allow for experts to collaborate remotely in surgical procedures where specific expertise is required or in settings where specialist surgeons may not be present, such as treatment in conflict zones.
6. **Tactile Internet:** Looking further into the future, the next wave of internet revolutionization will inherently require 5G connectivity and beyond and will change our lives in inconceivable ways. With the rise of the tactile internet, VR and AR technologies will become more prominent and advanced than most people can imagine. The tactile internet is an ultra-responsive network connectivity that can transmit touch and actuation in real time. Every aspect of society will

be impacted by this technological revolution and its effects on healthcare will be particularly pertinent. This enhanced haptic feedback will allow for great developments in telesurgery. Robotics, the use of which has grown rapidly in the medical sector, will become much more prominent still in the field of surgery; machines controlled by haptic gloves will transfer tactile data to the operating doctor, who can be situated a great distance away from the patient. Thanks to the near-zero latency, this will prove invaluable in many scenarios such as disaster relief and treatment of high-risk contagious patients.

3.1. FROM 'WEARABLE DOCTORS' TO DISTRIBUTED SENSORS FOR HOLISTIC HEALTHCARE

Doctors are beginning to have access to a whole new world of data, and patients can now be monitored from home. Whether wearable (and hence mobile) or stationary, connected medical devices allow medical professionals to access and analyse vast amounts of data in order to improve healthcare [21]. Examples of connected medical devices are illustrated in ***Figure 3***. The clear benefits of these 'wearable doctors' are: better patient care, improved insights, instant results, patients can stay home, quicker response time, and automatic supply control.

The challenges to overcome in order to allow for the widespread adoption of wearables are linked to safety and security [22]. In particular:

1. **Software Safety:** As medical devices become increasingly more complex and dependent on external software, the potential for errors also increases.
2. **Data Privacy:** The increasing connectivity of devices will allow for more attack points which hackers can target when attempting to access patient information.
3. **Device Security:** The risk to patient health and safety is a concern if hackers are able to gain remote access to devices.

Modern wearable devices that are in widespread use amongst the public can track our steps, sleep patterns and heart rate, and have been integrated into daily life in a matter of just a few years. We expect this to continue and accelerate over the coming years. The next generation of sensors might well switch from wearable devices to invisible and always-on sensors, embedded into the devices around us [8], as industries start striving towards ubiquitous connectivity between people and objects [23].

Digital healthcare companies have already begun incorporating these always-on sensors into devices capable

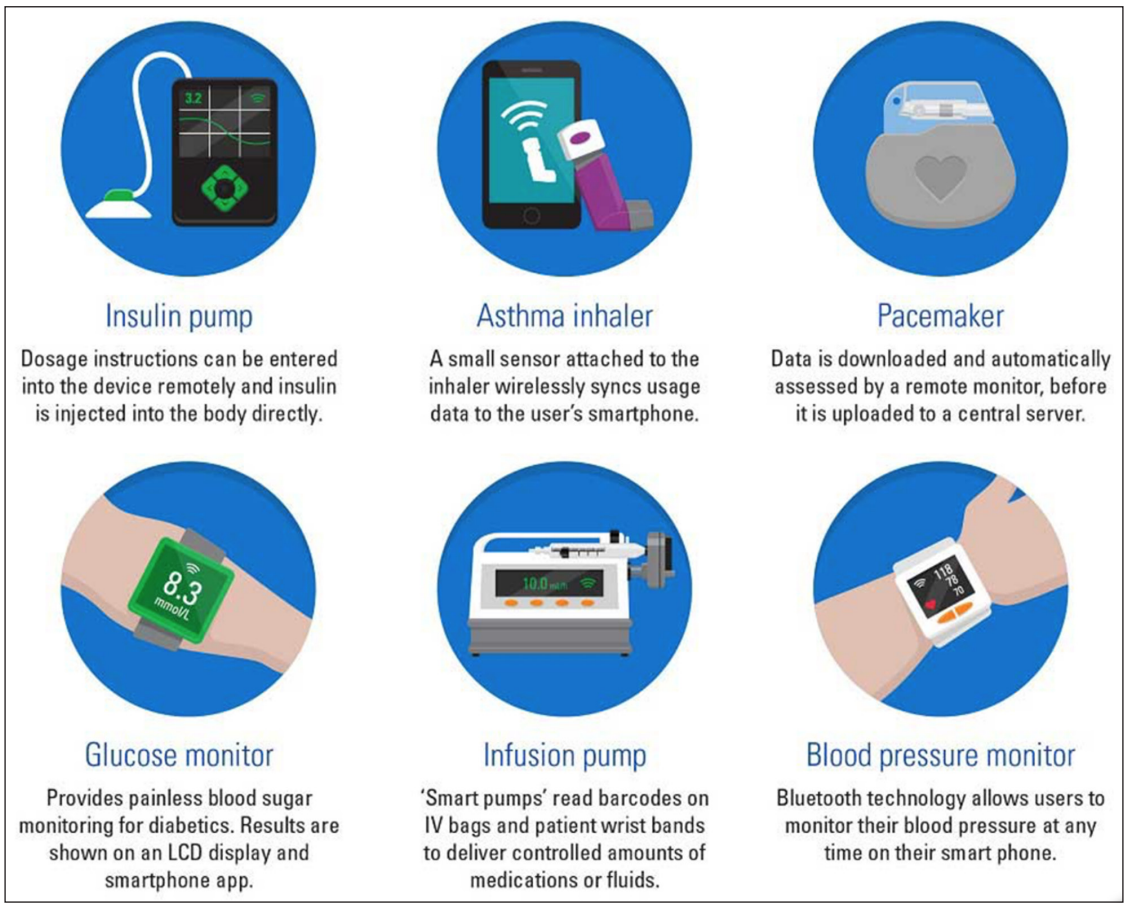

Figure 3 Types of connected medical devices. (Image credited to TÜV SÜD [21]).

of generating, gathering, and sharing their data. Advanced cognitive technologies could be utilised in an effort to analyse a large set of parameters to create personalised insights into an individual's health status. The use of data and personalised AI for this reason, could enable real-time micro interventions that allow us to predict and prevent sickness, long before catastrophic disease arises.

4. SOCIOECONOMIC IMPACTS OF 5G IN DIGITAL HEALTH

There is no question that 5G will bring major boosts to global economy in the coming years [17]: reports from Huawei, STL Partners and McKinsey predict that the technology will generate between $1.2–2 trillion in GDP for economies worldwide over the next decade [17, 24]. 5G advancements are directly addressing the diverse use cases available in IoT and in fact are moving onto Massive IoT (MIoT), focusing on truly vast numbers of connected devices. Applications of the MIoT are endless and include autonomous vehicles, industrial automation and indeed, telehealth.

Healthcare is one of the two industries set to benefit the most from advancements in connectivity with the other being manufacturing. These advancements offer massive commercial opportunities for hospitals, healthcare providers and the pharmaceutical industry. Further to healthcare workers, network operators and telecommunication providers too will benefit hugely. The European Union predicted the saving of €99 billion in annual healthcare spending and the addition of €93 billion to the EU GDP due to mobile health systems in 2017 [25]. According to the report of Huawei, 5G will allow healthcare professionals to treat over 850 million more outpatients a year by 2030 [24].

In the year 2035, one source predicts that global sales activity across various industries enabled by 5G has the potential to reach $13.2 trillion – about 5% of all global real output in that year [26]. When this is divided amongst the 16 major industry sectors (defined by the International Standard Industrial Classification of All Economic Activities, Revision 4 [27]), the healthcare sector will contribute a staggering $447 billion in 2035. Notably, there are three contributors to this economic benefit that 5G will bring to digital health: the sales of products and services enabled by 5G; the maturing of the 5G value chain through focused research and development efforts; and the potential for 5G to drive long-term, sustainable growth.

Investment in digital health is growing rapidly (***Figure 4***) [14]. Primitive mobile health systems are already in place around the world and their impacts can be seen; annually, remote monitoring of the elderly saves €2.4 billion in Sweden, €1.25 billion in Denmark and €1.5 billion in Norway [28]. Hence, the potential for net economic gain when more sophisticated forms of this technology are rolled out at scale is easy to see and the desire for interconnectivity and high-speed data transfer ensures its inevitability.

4.1. DECENTRALISED HEALTHCARE

The increased service capabilities enabled by 5G connectivity will contribute to the development and adoption of different healthcare models. In particular, this leads to the rise of decentralisation in healthcare and the shift from healthcare to homecare [6, 29, 30]. This will in turn result in increasing dependence on wearable and remote diagnostics and treatments, making 5G essential for reliable and secure service provision. As healthcare becomes decentralised, patient data becomes of paramount importance and will become increasingly centralised, thereby effectively turning hospitals into data hubs.

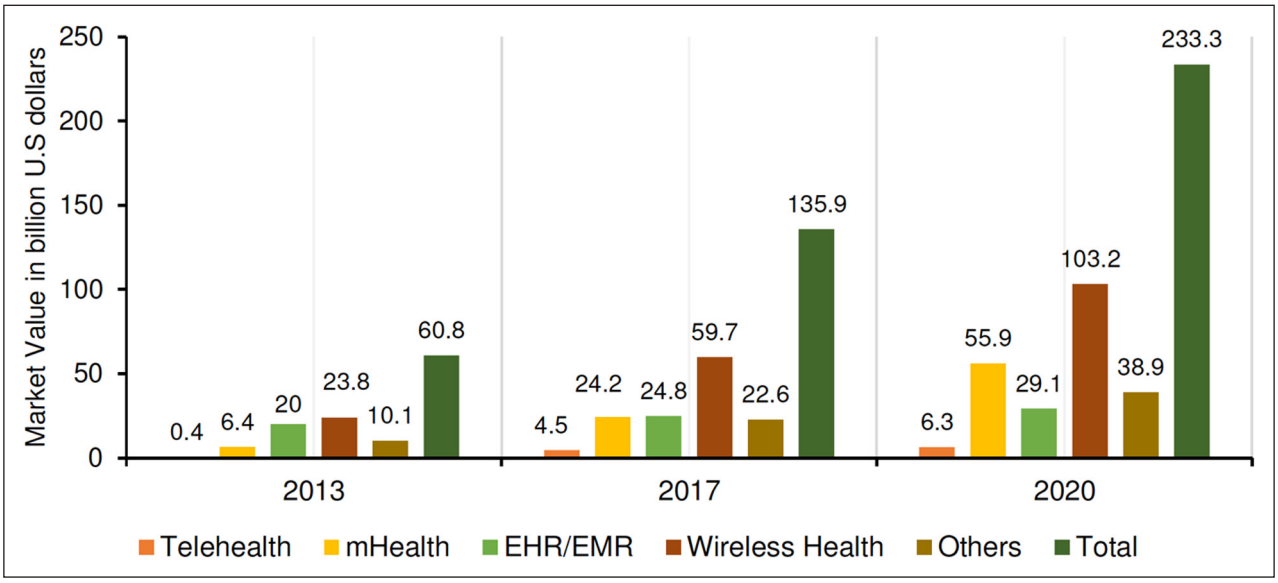

Figure 4 Digital health market value trends. (Image credited to the Latif *et al* [14]).

The subsequent socioeconomic impact of this is the increased sustainability of healthcare, considering current worries around demographic trends of an ageing society with high healthcare costs [19]. Decentralised healthcare also presents an opportunity to create improvements in patient's quality of life, for example in areas such as chronic disease management. Decentralising healthcare reduces the costs, both monetary and in time, to access medical care, by removing waiting lists and logistical problems based on patient location. A 5G-enabled decentralised healthcare model would allow for remote consultation, diagnosis and treatment, making specialised and quality healthcare more accessible and affordable.

Notably, there is evidence that patients and doctors alike welcome online, remote consultations. When the Covid-19 pandemic hit, many people felt uncomfortable attending in-person appointments and indicated they would welcome more digital health services. A recent survey indicated that 60% of UK and US consumers are either already using a digital health service or would use one in the future, if available [31]. Equally, 88% of general medical practitioners said they would like greater use of remote consultations in the future. The opportunities for use of 5G for digital healthcare are therefore particularly timely [12], and benefits of digital health appointments in the Covid-19 era also include increased accessibility to medical services and a reduction on the burden on medical professionals and hospitals [31].

This shift from healthcare to homecare and to a more decentralised model will also create new business opportunities. The future will focus on wellness and be managed by companies which proactively incorporate new roles which build value in the digital healthcare environment. These roles will be driven by greater data connectivity, interoperable and open, secure platforms, and increasing patient engagement. Successful companies will compete in one or more of the new business functions identified in ***Figure 5*** (which expands on the outer layer shown in ***Figure 2***) [8]. Three main categories will prevail over this: data and platforms, well-being and care delivery, and care enablement. Within these, ten main business functions are expected to emerge. Organisations' activities might spread over multiple functions, but multiple organisation types will be required to cover all archetypes in a category.

5. SPACE ASSETS FOR 5G

All the considerations presented in Section 3 (on the new 5G-enabled use cases) and Section 4 (on the 5G economy), assume that the availability of 5G is ubiquitous and that all customers (in this case, patients) have access to appropriate connectivity in order to benefit from the distributed healthcare system. Moreover, it also assumes that the myriad of medical instruments, devices, sensors and wearables will be securely connected all the time. For this to be the case, 5G will need to be universally available in city areas, as well as rural and remote areas, whether a patient is at home or walking outdoors and weather they are travelling by plane or by ship. For this reason, the provision of global ubiquitous, secure 5G communications will need to rely on a number of seamless interconnected networks. The 5G community is designing, standardising and implementing a layered network architecture which will drive the future of

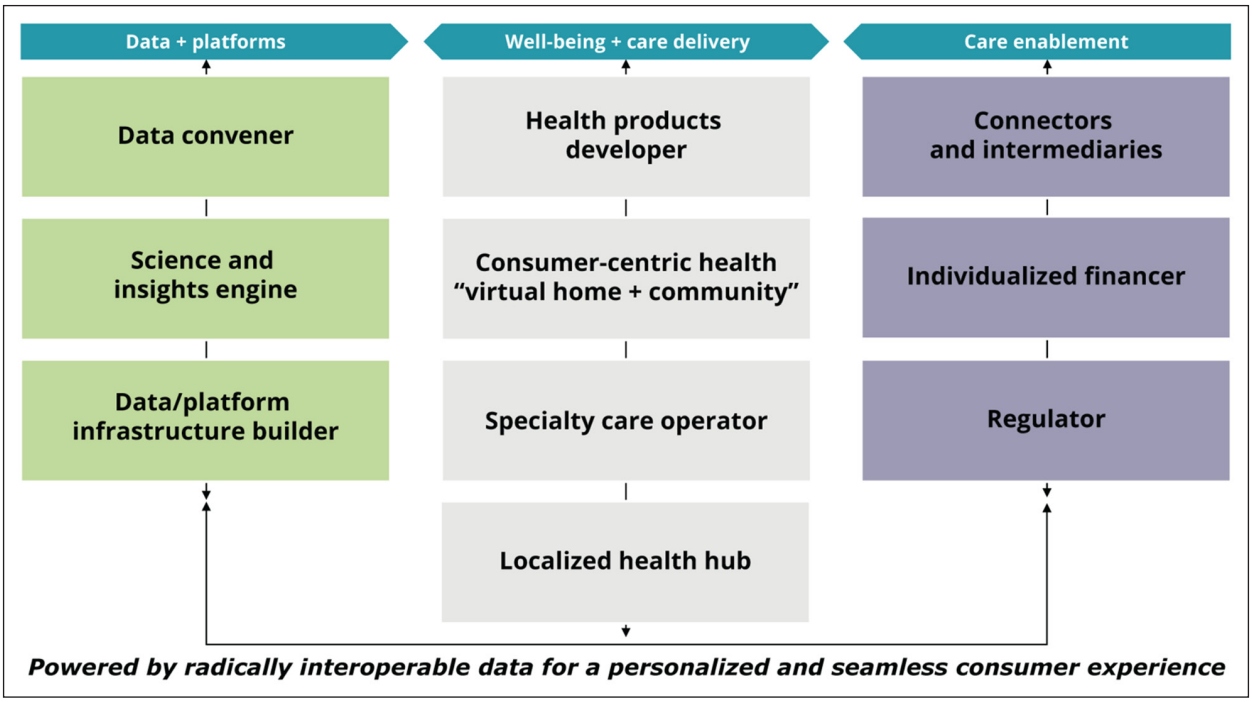

Figure 5 New business roles which are needed in the future of health. (Image credited to Deloitte Insights [8]).

telecommunications for 5G and beyond. The architecture makes use of several interconnected networks, in order to achieve the required attributes of global coverage, capacity and security [32]. Three layers are envisaged as shown in ***Figure 6***.

These three layers are defined as:

1. **The Terrestrial Layer:** Comprising the set of terrestrial communications for fixed and mobile users (including 4G, 5G, Wi-Fi, etc).
2. **The Airborne Layer:** Including high altitude platforms (HAPs) between 10 km and 50 km. Possible HAPs include 1) balloons 2) fixed-wing aircraft, and 3) unmanned aerial vehicles (UAVs). There can be Wi-Fi, 4G, 5G type of payloads providing connectivity to terrestrial users, and earth observation (EO) sensors for remote sensing purposes.
3. **The Space Layer:** Comprising of several different satellite constellations in different orbits. The different altitudes will determine whether the satellites are in geostationary orbit (GEO), medium earth orbit (MEO), low earth orbit (LEO), or highly elliptical orbit (HEO).

This layered 5G network architecture allows the delivery of secure ubiquitous connectivity globally. It therefore represents the connectivity fabric which underpins the digital transformation and provision of digital health services [6]. Further, it enables the shift to newly distributed patient-centric digital health ecosystems, integrating elements such as radical interoperability, big data analytics, cloud computing solutions, AI, blockchain and IoMT [33].

6. CONCLUSION

This paper provides a vision for the future of digital healthcare. It illustrates the profound digital transformation ongoing in the sector and emphasises the empowering effect of connectivity. In particular, it highlights the impact of 5G telecommunications in reshaping the provision of digital healthcare services and corresponding socioeconomic impacts. The evolution of the roles and business functions of the healthcare ecosystem is presented, which will enable new value chain models and actors, ultimately leading to a patient-centric health system which will result in a healthier population with reduced healthcare spending.

DISCLAIMER

Please note that the views, opinions and ideas expressed in this article are solely those of the authors and do not necessarily reflect the official policy or positions of the European Space Agency, the University of Toronto or The University of Sheffield.

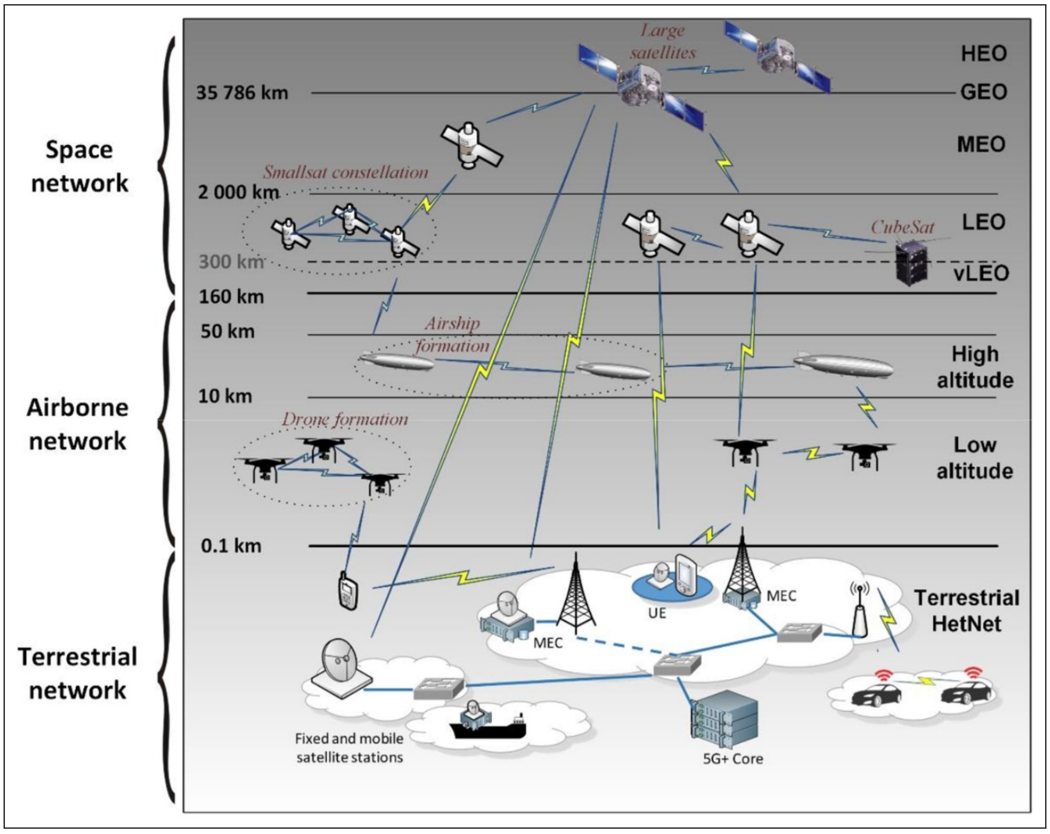

Figure 6 Schematic of the layered architecture of the 5G network. (Image credited to Höyhtyä *et al* [32]).

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Antonio Franchi
Telecommunications and Integrated Applications Directorate, European Space Agency, United Kingdom

Luca Franchi
Department of Electrical and Computer Engineering, University of Toronto, Canada

Thomas Franchi *orcid.org/0000-0003-2565-8098*
The Medical School, The University of Sheffield, United Kingdom

REFERENCES

1. **Dorsey ER, Topol EJ.** State of Telehealth. *New England Journal of Medicine*. 2016; 375(14): 1400. DOI: *https://doi.org/10.1056/NEJMc1610233*
2. **Ullah H, Nair NG, Moore A, Nugent C, Muschamp P, Cuevas M.** 5G Communication: An Overview of Vehicle-to-Everything, Drones, and Healthcare Use-Cases. *IEEE Access*. 2016; 7(1): 37251–37268. DOI: *https://doi.org/10.1109/ACCESS.2019.2905347*
3. Raconteur, A 5G world. *https://res.cloudinary.com/yumyoshojin/image/upload/v1/pdf/5g-2020-sep.pdf*, 2020 (accessed 3 January 2021).
4. University of Oulu, 5G Opens the Perspective for a New World. *https://www.oulu.fi/sites/default/files/186/5G_mediakit_ENG.pdf*, 2020 (accessed 2 January 2021).
5. **Chen M, Yang J, Hao Y, Mao S, Hwang A.** 5G Cognitive System for Healthcare. *Big Data and Cognitive Computing*. 2017; 1(1): 2. DOI: *https://doi.org/10.3390/bdcc1010002*
6. **Hamm S, Schleser A-C, Hartig J, Thomas P, Zoesch S, Bulitta C.** 5G as Enabler for Digital Healthcare. *Current Directors in Biomedical Engineering*. 2020; 6(3): 20203001. DOI: *https://doi.org/10.1515/cdbme-2020-3001*
7. **Ahad A, Tahir M, Sheikh MA, Ahmed KI, Mughees A, Numani A.** Technologies Trend towards 5G Network for Smart Health-Care Using IoT: A Review. *Sensors*. 2020; 20(14): 4047. DOI: *https://doi.org/10.3390/s20144047*
8. Deloitte Insights, Forces of Change: The Future of Health. *https://www2.deloitte.com/us/en/insights/industry/health-care/forces-of-change-health-care.html*, 2019 (accessed 2 January 2021).
9. Department of Health & Social Care, The Future of Healthcare: Our Vision for Digital, Data and Technology in Health and Care. *https://www.gov.uk/government/publications/the-future-of-healthcare-our-vision-for-digital-data-and-technology-in-health-and-care/the-future-of-healthcare-our-vision-for-digital-data-and-technology-in-health-and-care*, 2018 (accessed 3 January 2021).
10. AT&T Business, 5G & Healthcare: The Dawn of 5G Technology is Here. *https://www.business.att.com/content/dam/attbusiness/briefs/5g-healthcare-ebook-brief.pdf*, 2019 (accessed 2 January 2021).
11. Mordor Intelligence, Wearable Technology Market – Growth, Trends, and Forecasts (2020–2025). *https://www.mordorintelligence.com/industry-reports/wearable-technology-market*, 2019 (accessed 5 January 2021).
12. **Siriwardhana Y, Gür G, Ylianttila M, Liyanage M.** The role of 5G for Digital Healthcare against Covid-19 Pandemic: Opportunities and Challenges. *ICT Express*; 2020. Published online ahead of print. DOI: *https://doi.org/10.1016/j.icte.2020.10.002*
13. Centres for Disease Control and Prevention, Trends in the Use of Telehealth During the Emergence of the Covid-19 Pandemic – United States, January-March 2020. *https://www.cdc.gov/mmwr/volumes/69/wr/mm6943a3.htm*, 2020 (accessed 5 January 2021). DOI: *https://doi.org/10.15585/mmwr.mm6943a3*
14. **Latif S, Qadir J, Farooq S, Imran MA.** How 5G (and Concomitant Technologies) will Revolutionize Healthcare. *Future Internet*. 2017; 9(4): 93. DOI: *https://doi.org/10.3390/fi9040093*
15. **Esteva A, Kuprel B, Novoa RA, Ko J, Swetter SM, Blau HM, Thrun S.** Dermatologist-Level Classification of Skin Cancer with Deep Neural Networks. *Nature*. 2017; 542(1): 115–118. DOI: *https://doi.org/10.1038/nature21056*
16. Research and Markets, Cognitive Computing and Artificial Intelligence Systems in Healthcare. *https://www.researchandmarkets.com/reports/3508221/cognitive-computing-and-artificial-intelligence*, 2015 (accessed 5 January 2021).
17. McKinsey Global Institute, Connected World: An Evolution in Connectivity Beyond the 5G Revolution. *https://www.mckinsey.com/~/media/mckinsey/industries/technology%20media%20and%20telecommunications/telecommunications/our%20insights/connected%20world%20an%20evolution%20in%20connectivity%20beyond%20the%205g%20revolution/mgi_connected-world_discussion-paper_february-2020.pdf*, 2020 (accessed 3 January 2021).
18. Vodafone, 5G Connects Ambulances to Hospitals for more Accurate Diagnosis and Critical Treatment. *https://www.vodafone.co.uk/business/5g-for-business/5g-customer-stories/connected-ambulance?fbclid=IwAR1Iqv_8o8_H0MHxvEesITE5NIfL107Zxtl3FhZNayv0oQison3Iwqudtxw*, 2020 (accessed 5 January 2021).
19. **Li D.** 5G and Intelligence Medicine – How the next Generation of Wireless Technology will Reconstruct Healthcare? *Precision Clinical Medicine*. 2019; 2(4): 205–8. DOI: *https://doi.org/10.1093/pcmedi/pbz020*
20. STL Partners, 10 5G Healthcare Use Cases Transforming Digital Health. *https://stlpartners.com/digital-health-telecoms/10-5g-healthcare-use-cases*, 2017 (accessed 3 January 2021).

21. TÜV SÜD, The Future of Healthcare. *https://www.tuvsud.com/en-gb/resource-centre/stories/the-future-of-healthcare*, 2018 (accessed 2 January 2021).
22. TÜV SÜD, Wearable Doctors. *https://www.tuvsud.com/en-gb/resource-centre/stories/wearable-doctors*, 2016 (accessed 2 January 2021).
23. **French AM, Shim JP.** The Digital Revolution: Internet of Things, 5G, and Beyond. *Communications of the Association for Information Systems*. 2016; 38(1): 840–850. DOI: *https://doi.org/10.17705/1CAIS.03840*
24. IT ProPortal, 5G will Bring a Major Boost to the Global Economy over the Next Decade. *https://www.itproportal.com/news/5g-will-bring-a-major-boost-to-the-global-economy-over-the-next-decade/#:~:text=A%20new%20report%20from%20Huawei,also%20help%20protect%20the-%20environment*, 2019 (accessed 5 January 2021).
25. PwC, Socio-Economic Impact of mHealth: An Assessment Report for the European Union. *https://www.gsma.com/iot/wp-content/uploads/2013/06/Socio-economic_impact-of-mHealth_EU_14062013V2.pdf*, 2013 (accessed 5 January 2021).
26. IHS Markit, The 5G Economy: How 5G will Contribute to the Global Economy. *https://www.qualcomm.com/media/documents/files/ihs-5g-economic-impact-study-2019.pdf*, 2019 (accessed 2 January 2021).
27. United Nations, International Standard Industrial Classification of All Economic Activities (ISIC) Revision 4. *https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf*, 2008 (accessed 2 January 2021).
28. The Boston Consulting Group, The Socio-Economic Impact of Mobile Health. *https://www.telenor.com/wp-content/uploads/2012/05/BCG-Telenor-Mobile-Health-Report-May-20121.pdf*, 2012 (accessed 5 January 2021).
29. Global 5G, 5G for Health. *https://global5g.org/verticals/5g-health*, 2019 (accessed 2 January 2021).
30. Ericsson Consumerlab, From Healthcare to Homecare: The Critical Role of 5G in Healthcare Transformation. *https://www.ericsson.com/49e91e/assets/local/reports-papers/consumerlab/reports/2017/healthcare-to-homecare_screen_aw2.pdf*, 2017 (accessed 2 January 2021).
31. Raconteur, Under Pressure: Making the Case for Virtual Appointments. *http://res.cloudinary.com/yumyoshojin/image/upload/v1/pdf/future-healthcare-2020-aug.pdf*, 2020 (accessed 2 January 2021).
32. **Höyhtyä M, Corici M, Covaci S, Guta M.** 5G and Beyond for New Space: Vision and Research Challenges. *Presented at the International Communications Satellite Systems Conference (Okinawa, Japan)*. *https://www.researchgate.net/publication/335292080_5G_and_Beyond_for_New_Space_Vision_and_Research_Challenges*, 2019 (accessed 2 January 2021).
33. Deloitte Insights, Digital Transformation and Interoperability. *https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/life-sciences-health-care/lu-lshc-digital-transformation-and-interoperability.pdf*, 2020 (accessed 2 January 2021).

TO CITE THIS ARTICLE:
Franchi A, Franchi L, Franchi T. Digital Health, Big Data and Connectivity: 5G and Beyond for Patient-Centred Care. *International Journal of Digital Health*. 2021; 1(1): 1, 1–10. DOI: *https://doi.org/10.29337/ijdh.24*

Submitted: 07 January 2021 Accepted: 22 January 2021 Published: 01 March 2021