

**Technology, Media, and
Telecommunications
Predictions 2021**
India Edition

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Foreword

We can't talk about 2021 without mentioning COVID-19. All of our TMT Predictions topics for this year were shaped to some extent by the pandemic. We hope that during 2021, we will be closer to the end of the pandemic than the beginning, focusing on thriving in the future rather than responding to the present.

Across multiple parts of the Technology, Media, and Telecom (TMT) ecosystem, observers have been repeating some version of the comment, "There have been five years of change in five months due to the pandemic." COVID-19 has been a catalyst—an unwelcome one, but still a catalyst—for needed changes across the TMT landscape.

A catalyst is a substance that causes a chemical reaction to occur more rapidly than it would have without. Sometimes, only a tiny amount of catalyst can trigger a large change. In the same way, the SARS-CoV-2 virus, which is only 100 nanometers across and weighs one trillionth of a milligram, has catalyzed considerable changes in many facets of TMT.

Some of these changes happened extremely quickly. Movements to the cloud, to video visits for medicine, and to the intelligent edge were already underway in 2019, but they have been accelerated by years or even decades because of the pandemic. We expect rapid evolution in these three areas to continue through 2021.

Other parts of the TMT industry were also shaped by the pandemic, although not to the same extent. Upgrades to 8K TVs may be accelerated by lockdowns and the rise in time spent watching video. Digital

reality headsets helped enterprises train workers and school educate students virtually when COVID-19 made meeting in person difficult. Misinformation flourishes against a backdrop of uncertainty, and myths about 5G's health risks surged. And the hyperquantification of athletes may make sports viewing more compelling in a time when stadiums are less accessible.

Faster change isn't always positive change, of course. But many of the trends accelerated by the pandemic look likely to make the world a better place. More gender balance in sport is a good thing—end of story. Medical video visit technology that works in the developed world during a lockdown will likely lead to more and better medical access in the developing world and remote areas. Greater use of the cloud, and of open or virtual radio access network (RAN) solutions, may make software and cellular service more affordable for the economically disadvantaged ... and may also do so more sustainably, helping not just people but the planet too.

In a chemical reaction, when a catalyst is removed, the reaction returns to its slower rate. Will the post-pandemic world see change, disruption, and innovation decelerate from current levels? Or will the acceleration induced by COVID-19 persist for the long term—perhaps even permanently?

Welcome to TMT Predictions 2021.

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Let the games begin

India is set to witness a boom in online gaming as several favorable factors converge

Globally, the video game industry dwarfs the cinema box office (being around four times the size of the box office revenues).¹ However, in India, the gaming industry is less than half of box office collections.² This gap is expected to narrow, with several factors converging and providing a tailwind to the gaming industry.

The Indian online gaming industry was estimated to be US\$1.1 billion in 2019³

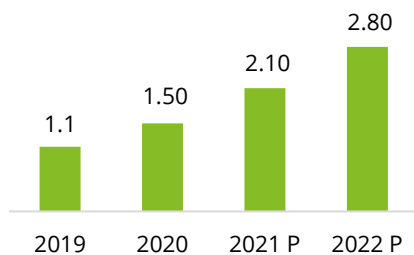
with ~5% share of the Indian Media and Entertainment (M&E) industry.⁴ We predict that the online gaming industry in India will continue to grow rapidly. The industry is expected to grow at a CAGR of 40% until 2022, taking the market size to US\$2.8 billion by 2022, and strengthening the sector's share of total M&E by 4–5%.⁵ This growth would be majorly driven by mobile gaming as 85% of the online gaming in India takes place on mobile.⁶

The factors that will drive this rapid growth of the industry are discussed below.

The pandemic push

Even before the COVID-19 pandemic, online gaming was on a growth path, extending its reach to wider and diverse audiences. The alluring offering of online gaming to engage with other gamers worldwide, ability to play on any new-age computing device, attend in-game events, complete rewarding tasks, and post accomplishments on social media has spurred innovative business models and stirred consumer behavior.

Figure 1: Indian gaming market (US\$ billion)



Source: Frost & Sullivan, Deloitte analysis

Gaming was already amongst the top five activities carried out on mobile devices in 2019.⁷ Then the pandemic and ensuing restrictions provided a turbo boost to the industry.

Of the universe of consumer choices for entertainment, here is how gaming got a boost:

- At the first level, several traditional recreational and entertainment options became unavailable. Options such as live concerts and movie theatres thus fell out of the set of possible choices.
- At the second level, some of the options that could be consumed from the safety of one's home did not allow for creation of new content. For instance, traditional television and video OTT platforms had their libraries, but could

not produce much new content due to COVID-19-related restrictions. Thus, their utility decreased with time as consumers viewed old episodes while new episodes were coming slow.

- Only a few options — notably gaming and anime/animation — could support creation as well as consumption in the “new normal”, thus gaining an edge over other entertainment options.

In India, it is reported that engagement, as measured by time spend on gaming apps, increased by 21% during the initial national lockdown,⁸ with the total customer base crossing 300 million users.⁹

While the arrival of vaccines and resumption of economic activities may result in a levelling off or even decline in the average time spent on video gaming, the industry would already be in a higher gear.

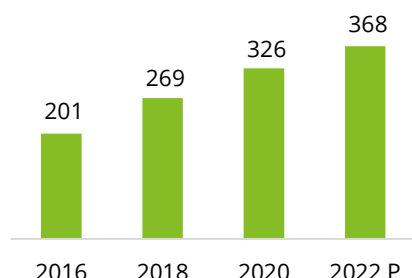
Influence of socio-economic parameters

India has witnessed a number of socio-economic transitions over the past decade, with some driven by policy (notably endorsing of micro-transaction payment systems post-demonetization). Key drivers that would lead to the growth of domestic consumption of gaming in India are mentioned below:

Demographics

Demographic dividend: India is one of the top five mobile gaming markets in the world, with 13%¹⁰ share of global game sessions, and is expected to add ~40 million online gamers during 2020–22.¹¹

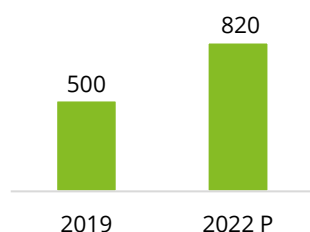
- About 65% of the Indian population (1.3 billion) is below 35 years of age. By 2022, the median age of India will be just 29, which is quite young as compared with China (37) or Japan (48), and would offer a significant demand base for gaming companies in India.¹²
- Rural areas and women are also increasingly coming into the gaming fold.¹³

Figure 2: Number of online gamers in India (million)

Source: The Power of Mobile Gaming in India, MMA and Kantar IMRB in association POKKT

Smartphone penetration

The number of smartphone users in India is expected to reach 820 million by 2022.¹⁴ Along with affordability, newer smartphones offer advanced capacity and features. These features include chipsets for faster processing, Graphics Processing Units (GPUs) for immersive graphics, large High Dynamic Range (HDR) capable screens, and extended battery capacity. These allow users to play games that were previously inaccessible and provide an enhanced gaming experience.

Figure 3: Smartphone users in India (million)

Source: India Cellular and Electronics Association (ICEA) report

Affordable data services

India has more than ~500 million active internet users, making it the second-largest online market in the world.¹⁵ It has one of the world's most affordable mobile data plans, which has also promoted internet penetration in rural India,

including high-speed 4G mobile networks with low latency. This helps players participate in real-time multiplayer games.

Improving disposable income

The Gross Domestic Product (GDP) per head (at PPP) in India is expected to increase from US\$5,840 in 2016 to US\$7,302 in 2022.¹⁶ Gross National Disposable Income (GNDI) of India has already nearly doubled from 2012–13 to 2018–19 with per capita GNDI increased from INR 82,408 to INR 144,429 during the same period.¹⁷ Increase in per capita income would lead to a rise in willingness to pay for digital services.¹⁸

Deeper adoption of digital payments

Cash was the king in the Indian economy before the pandemic. However, demonetization (in 2016) followed by the pandemic (in 2020) have diminished the popularity of cash and made cashless transactions increasingly popular among people.

According to National Payments Corporation of India (NPCI), Unified Payments Interface (UPI) payments took three years to reach one billion transactions in October 2019 compared with just one year to reach the next billion mark.¹⁹ This widespread adoption of digital payment solutions has greatly reduced friction and presented a vehicle to monetize video games. Digital payment solutions enable in-app purchases that games increasingly rely on; this is the revenue model for gaming worldwide.

Innovative consumption models

The gaming business model has transitioned from a model dependent on download volumes and advertisements to one with diversified revenue streams built on consumer engagement and elevated experience levels:

- In-game revenue streams, such as chargeable expansion packs, exclusive customisable avatars, virtual coin packs, and advanced features

- Ad revenue from banners, multimedia, and product placements
- Subscription-based models gaining popularity, with players paying a monthly fee in exchange for access to ad-free content and upgrades; subscription models resulting in an increase in gaming time by about 40%, in addition to providing a recurring revenue stream²⁰

Online gaming industry/market strides

Key gaming segments

Gaming in India is expected to grow at a significantly faster rate (CAGR of 40%) than the global gaming industry (CAGR of 9%).²¹ In 2019, 5.6 billion mobile game applications were downloaded in India; this number is the highest in the world.²²

The key segments witnessing higher growth rates are mentioned below:

Real Money Gaming (RMG)

In India, RMG is expected to grow at a CAGR of 40% from 2020–22.²³ Key trends include growing support for games such as poker and rummy (to be recognized as games of skills and thus legal). Further, games with an Indian connect allow for an engaging gaming experience and would experience improved adoption rate from rural areas.²⁴

E-sports

- In India, e-sports revenue is expected to rise at a CAGR of 36% over the next three years.²⁵ Gamers spend more time watching other people play video games than they do watching traditional sports on TV. An Indian gamer spends, on an average, 3.6 hours per week in watching e-sport tournaments.²⁶
- This growth in e-sports is driven by widespread availability of devices and initiatives by e-sports firms, enabling participation in tournaments via cafés rather than having to individually own equipment.

Fantasy sports

Fantasy sports revenue increased ~9 times in the pre-pandemic years between 2017–18 and 2019–20, reaching INR 165 billion.²⁷ Real-world events, such as the Indian Premier League (IPL), fuel viewers' interest to try their hand at fantasy sports. This came to the fore recently, with fantasy sports company Dream11's bid of INR 2.22 billion for the IPL 2020 title sponsorship outbidding established bidders.²⁸

Game development capability

Recent regulatory interventions in India have led to a ban on major international games, providing opportunities for indigenous alternatives to grow and expand.

Publishers are releasing engaging content with compelling play modes. The budding gamification capabilities are also seeing collaborative applications in industries such as education and video streaming. Recognizing the capability, global game developers are viewing India as a global hub, along with possible cost advantages.

New technologies

Rise of cloud gaming:

Cloud gaming services empower gamers to forgo the requirement of specific hardware to access the games and allow access from anywhere using a capable device. This trend may play out in the longer term in India (not in short-to-medium period).

Data analytics:

Analytics on user behavior enables publishers to gain key insights to help improve user retention, in-app purchases, and user experience.

AI/ML and XR:

Technology such as AI has historically been used in gaming. However, the scale and depth at which these technologies are used is expanding.

Ecosystem development**Local and foreign investment**

Recognizing the potential, there is a steady flow of local and foreign

investments, attracting more than US\$450 million from 2014–20 and over 400 active start-ups.²⁹ Some notable investments include the following:

Table 1: Local and foreign investments

No.	Investments
1	Pegasus Tech Ventures, Venture Highway, Luminaire Capitals, and other investment firms infused US\$90 million in 2020 in MPL gaming app ³⁰
2	DSG, Jetline, and Triveni Engineering & Industries invested US\$40 million in Jetsynthesys ³¹
3	PayTM and Alibaba Group formed a joint venture to launch Gamepind ³²
4	Tencent, Steadview, Kalaari Capital, Think Investments, and Multiples Equity invested in Dream11 ³³
5	Reliance Jio invested in Mobile Gaming Startup Krikey ³⁴

Education and job creation

Recognizing the industry's importance, India's prime minister is encouraging the development of digital games inspired from the Indian culture. The Union Ministry of Education is taking initiatives to create jobs in the digital gaming industry to augment the dearth of talent for indigenous game design and development. The Information and Broadcasting Ministry is working on developing a center for training and content creation in animation.³⁵

On the policy front, the recently announced drafting of a national

animation, visual effect, and Gaming and Comic (AVGC) policy is expected to give the industry the much needed regulatory support, encouraging investment and expansion.

Additionally, the Union government has announced plans to support young online gamers to generate job opportunities by showcasing their talents through national-level hackathons.³⁶

These key industry and government initiatives are expected to lay the foundation for job creation and enabling job seekers to consider gaming as a career choice.

The bottom line

The Indian online gaming sector has witnessed a positive momentum over the past few years, adding ~120 million users during 2016–20.³⁷ Even before the pandemic, online gaming was on the growth path being driven by India's evolving socio-economic factors, such as improving disposable income, rising rural user segments, affordable world-class smartphones, increased adoption of micropayment solutions, and a 500 million large internet user base.³⁸ Undoubtedly, the pandemic has propelled the industry's growth by changing consumers' buying behavior, increasing digital adoption, and positioning gaming as a go-to medium for entertainment. Games' quality has improved. Players are expected to continue using new technology and analytics to improve user experience and engagement, bringing in engaging content for every age group and demographic background.

This would not only attract demand from foreign studios but also bring in investment into domestic market – which has grown 78% between 2019 and 2020.³⁹ Policy level and employment-related initiatives would ensure any gaps in the talent pool are filled and enable the industry to reach closer to its potential.

Some of the pandemic-infused momentum may gradually taper as that happens with most industries. However, the gaming sector has healthy growth factors and indicators that would take it to the next level.





The cloud cover intensifies in 2021 and it is a bright future

Deloitte predicts 2021 to be an 'overcast' year – with a more broad-based cloud adoption across the government and public sectors at large, corporates, Small and Medium Businesses (SMBs), and start-ups. Some of this has been in the works for a while – hyper-scale cloud providers landed in India circa 2015 to 2017, cloud awareness and adoption have been increasing. The COVID-19 pandemic

has changed the way we interact, live, and work. However, this year, we observe a number of unprecedented catalysts that have accelerated and will continue to accelerate demand for cloud in India. These include the following:

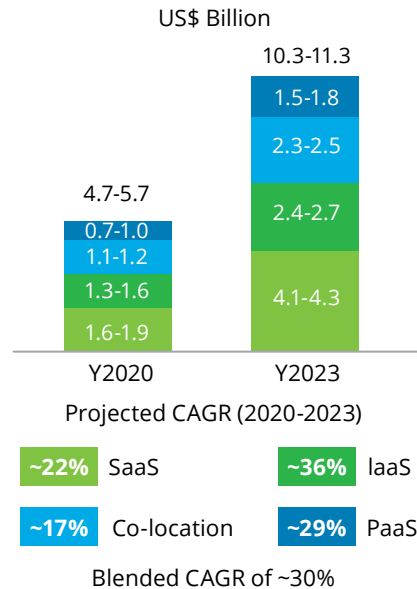
- Organizations have had to transform themselves rapidly to adapt to the 'new normal', which has entailed accelerated enablement of virtual

and digital business models (from a customer lens) and virtual and digital operating models (from an internal lens). Cloud, associated exponential technologies and business applications (such as everything as a service, NoOps, API economy and data science) are expected to be key enablers underpinning this transformation

- The Government of India's digital initiatives, cloud adoption push, regulatory shifts, and several proposals around incentives for cloud and data center players (e.g., promotion of data center parks, single window clearances, GST subsidies/refunds, aiding, and subsidizing land acquisition, and subsidies for power, water, and fiber connectivity)
- Maturity in associated ecosystem that includes telecom network modernization, fiberization, 5G, and power infrastructure, resulting in data centre expansion
- Increasing demand with preference for agile, loosely coupled, asset light models across the digital and technology brethren

Given these various supply and demand tailwinds, Deloitte predicts the cloud and co-location market will grow at a CAGR of 30% over 2020–23 to reach a market size of US\$10.3–11.3 billion⁴⁰ up from US\$4.7–5.7 billion in 2020. Infrastructure as a Service ("IaaS"), Software as a Service ("SaaS") and co-location are expected to constitute the largest opportunities. Significant acceleration in demand is expected from cloud-based support services, such as collaboration tools, identity management, end-point encryption, and cyber security. Enterprises will continue to migrate their applications and workloads from on-premise data centers to cloud solutions to use IT effectively, optimize on IT asset costs, accelerate innovation, and enable virtual ways of working.

Figure 4: Projected growth in India's cloud and co-location market



Continue to see some strong market activity in the underlying data center space in India. 2019-20 saw over a dozen transactions valued in excess of US\$ 1.5 billion across global and local private equity and data center players. Hyperscale cloud providers are expected to deepen their footprint in India. Some newer market participants have emerged that will be interesting to watch out for.

Business applications

Underpinning this adoption is business transformation, powered by cloud. Business and financial outcomes which are being enabled by new business models, doing more with less and radically simplifying the ways of working are becoming more apparent and meaningful to decision-makers. Below are a few cloud-led mandates that we see emerging in boardroom conversations:

- IoT and edge computing
- Data and application modernization, including 'serverless'
- exponential computation and analytics

IoT and edge computing

With the drive and need for digitally transforming organizations at a much wider scale and pace, we see an ever-increasing need for integrating various parts of the organization and connecting multiple end points with minimum latency, augmented with Artificial Intelligence (AI)/Machine Learning (ML). IoT and edge computing are the building blocks for enabling such transformations. We are seeing diverse deployment use cases emerging in areas such as smart cities, electric vehicle charging, smart surveillance, and smart manufacturing. These use cases are expected to grow in the next few years.

The rise of edge computing can in part be attributed to the dramatic increase in the number of IoT devices connected to the internet every second. Edge computing allows data generated by IoT devices to be processed closer to its sources instead of sending it across networks.

Expected proliferation of 5G capabilities will add more muscle to edge computing capabilities and serve as a power boost. In the next few years, we are expecting to see many IoT providers diversify their focus equally on the consumer marketplace. A plethora of IoT-generated end points would also mean massive transactional volumes and a potentially wider proliferation of cyber risks. As a result, we see a need for emergence of new IoT security models to manage this.

'Server less' or 'Function as a Service' (FaaS)

Serverless, also known as FaaS, is the next evolution from monolithic application architecture after service-oriented architecture and micro-services architecture.

Serverless is a technology that implements functions in the cloud on a need basis. Enterprises rely on serverless computing because it provides space

to work on core products without the pressure to operate or manage servers. The real innovation of these systems is the possibility to run applications without worrying about the underlying infrastructure. For instance, this would result in provisioning, scalability, and server management being automatically administered, with enormous advantages for flexibility and performance, at a lower cost.

Going serverless allows organizations to optimize capital expenditures and overall Total Cost of Ownership (TCO). In addition, serverless infrastructure reduces the need for human resource deployment as a focus on batch processing decreases. Together, these reduce expenses significantly.

Serverless stacks from hyperscale cloud providers create a robust and intuitive environment for the developer community at large. This further offers a large set of 'on cloud capabilities,' which can be used as needed, enabling developers to run at scale economically and deliver highly agile application development outcomes. Adoption of serverless computing allows organizations to shift from the restrictive, time-consuming, and draining traditional workflows and engage in event-based computing. Now, coders can just write algorithms and the serverless provider can take care of the data storage and computing needs. This will not only reduce the time of transaction processing and the cost of DevOps, but also free up the time and space for coders to take on other business logic tasks. Serverless computing gives organizations the freedom to focus on their core business offerings and deal with only low-level OS issues. Deployers, coders, and top management can use this time, money, and opportunity to develop competitive offerings. This can help the organization overtake competitors.

Exponential computation and analytics

Embedding exponential computation and analytics as a key enabler to decision making is also seen driving numerous use cases for cloud adoption. On the cloud, XaaS platforms enable wider and deeper business solutions around AI, ML, deep learning, neural networks

and advanced data science. This drives significant business outcomes, including a better 360° view of customer, more precise personalization, ability to manage demand elasticity, enable real-time analytics to drive behavioral sales, and enhance the overall omni-channel customer experience.

The bottom line

The year 2021 will be a watershed year for the cloud and data center market in India. COVID-19, acceleration in digital and virtual adoption by organisations, the regulatory and policy push, and the significant investments by existing data center players, hyperscale cloud providers and new emerging market participants are unprecedented catalysts pushing the market forward. Deloitte predicts the growth of the cloud and co-location market at a CAGR of 30% to reach US\$10.3–11.3 billion by 2023.

The key cloud mandates we see emerging in the coming year are IoT and edge computing, data and application modernization (specifically 'serverless'), and exponential computation and analytics. New business models will emerge in India to facilitate the deployment of edge through cloud platforms using AI/ML capabilities. The rise of edge computing can in part be attributed to the rise in the number of 'connected' devices connected to the internet every second. The importance of IoT security will increase on the back of plethora of endpoints, transactional volumes and potentially wider proliferation of cyber risks. Serverless computing with its high deliverability, coupled with the immense opportunities it promises, makes it a must adopt. India will continue to lead the pack in serverless adoption.





Gaining an intelligent edge

Edge computing and intelligence could propel tech and telecom growth

Rising from decades of instrumentation, automation, and connectivity, the intelligent edge is maturing into a revolutionary set of capabilities that are already transforming some of the largest technology and communications companies on the planet. Although market estimates vary considerably,⁴¹ Deloitte predicts that in 2021, the global market for the intelligent edge will expand to US\$12 billion, continuing a CAGR of around 35%.⁴² Expansion in

2021 will be driven primarily by telecom service providers by further deploying the intelligent edge for 5G networks, and by hyperscale cloud providers optimizing their infrastructure and service offerings. These highly capitalized leaders are establishing the use cases and best practices that may make it easier for companies across multiple industries to attain the capabilities of the intelligent edge. By 2023, 70% of enterprises may likely run some amount

of data processing at the edge.⁴³ As one leading Graphics Processing Unit (GPU) manufacturer has stated, “We’re about to enter a phase where we’re going to create an internet that is thousands of times bigger than the internet that we enjoy today.”⁴⁴

Though challenges and headwinds exist, we believe that the intelligent edge is poised to transform the computing landscape, propelling the world’s largest technology companies towards the next generation of connectivity and operational efficiency. By bringing powerful computing capabilities closer to where data originates and needs to be consumed, the intelligent edge is expected to unlock potential for faster, less expensive, and more secure operations across several use cases ranging from autonomous vehicles to virtual reality to the Internet of Things (IoT)—helping to accelerate the Fourth Industrial Revolution.⁴⁵

What is the intelligent edge?

The intelligent edge is the combination of advanced wireless connectivity, compact processing power, and artificial intelligence (AI) located near devices that use and generate data.⁴⁶ It represents an evolution and convergence of trends in industrial monitoring, automated manufacturing, utility management, and telecommunications, further amplified by cloud computing, data analytics, and AI. The intelligent edge puts these latter capabilities physically near where data needs rapid analysis and response, enabling that data to be acted on directly or filtered to push only the most important bits to the core. In particular, the intelligent edge’s ability to bring cloud capabilities to remote operations could greatly amplify their performance.

The monumental rise of artificial intelligence and the evolution of computation to support it are critical enablers, further driving tectonic shifts in the semiconductor industry.⁴⁷ Graphics

processing units (GPUs) have been moving into data centers, and dedicated AI chips are reaching out to the edges, including devices to operate on incoming data immediately.⁴⁸ Advanced connectivity ties them all together, while virtualization enables services to seamlessly run across a web of diverse and dynamic components, from the cloud to the edge. Indeed, effective planning and implementation of an intelligent edge strategy may require coordination and orchestration of multiple ecosystem providers.

The monumental rise of artificial intelligence and the evolution of computation to support it are critical enablers, further driving tectonic shifts in the semiconductor industry.

This rise of the intelligent edge will likely drive the evolution of service architectures to become more location-driven, decentralized, and distributed. The intelligent edge does not replace the cloud or data centers but, rather, is an element within a holistic cloud-to-edge architecture.⁴⁹ Some components of a service will run in a centralized cloud, others at the data center, and more yet at the edges on sensor arrays, autonomous vehicles, and potentially billions of machine endpoints. The ways that computation operates on different parts of the data journey, where it operates, and the differing requirements those operations place on connectivity and speed may reshape how services are architected by distributing components based on their needs.

There are challenges to overcome, however standards and best practices have yet to cohere, and issues with interoperability and security will likely become more visible. The intelligent edge today combines solutions from telecoms, hyperscalers, and technology providers, and effective implementation requires coordination and integration across multiple sectors. Who owns which pieces? Who makes the most of their capabilities? Who will deliver the best end-to-end solutions for the rest of the market? The answers to these questions could shape the landscape for years.

Why is the intelligent edge important?

For businesses with data-driven use cases, the intelligent edge offers the following key capabilities:⁵⁰

- More efficient use of bandwidth and greater network visibility which can lower costs
- Resilience against poor, unreliable, and lost connectivity due to lower dependency on wide-area networks (WANs)
- More control over data triage, normalization, residency, and privacy through the ability to keep more data local rather than needing to transmit it across the network to the core
- Support for low-latency use cases and fast response times
- Greater automation and autonomy

With these capabilities, the intelligent edge can add greater visibility across operations, support faster data analysis and real-time response, and enable better automation and more dynamic systems. If certain microservices require very low latency and high security, such as facial recognition for facility access, they can execute at the edge rather than in the cloud. This can enable much tighter decision loops, reducing the costs and security risks of network transit. The edge can send the most important bits to the core and the core can manage the edge.

The intelligent edge can support large-scale transformational solutions that could radically evolve manufacturing, logistics, robotics, mobility, and consumer electronics.⁵¹ For instance, an intelligent edge system can shift supply chains from somewhat fragile, linear systems to more programmable, responsive, and adaptive digital networks able to reshape themselves to address changing demands and disruptions.⁵² As another example, utilities and similar organizations could use the intelligent edge to connect AI-enabled drones to address mounting risks posed by aging infrastructure,⁵³ which would make identifying and addressing those risks much faster. One Norwegian oil rig has already deployed a remote autonomous robotic dog on that can patrol the rig and visually inspect for issues such as gas leaks.⁵⁴ These devices can be deployed 24/7 to map and monitor assets, flag problems, and alert the rig's networks and crews of potential risks.

The advantages of using the intelligent edge for such operations can be significant. Consider how an automated drone could inspect a pipeline for defects. With cloud, the drone might fill its local storage with video of a pipeline inspection, then return to its base station. It would then upload the video to a remote data center, potentially sending gigabytes of information over the network and requiring significant time to do so. The cloud would apply machine learning (ML) to evaluate the data for defects and, upon spotting them, return that information back to the pipeline site to provoke a response: Treat the defect and possibly reroute flows.

With edge intelligence, the same AI/ML inference algorithms that the cloud uses to evaluate the video can be run directly on the drone. Instead of scanning and analyzing the entire video, the drone could operate on a small, near-real-time buffer of the video feed to classify defects. When it identifies a defect, the drone can immediately notify nearby

crews to treat the problem. Only frames with defects are archived in the cloud to feed models and training sets, which can then update other drones in the field for better spotting. This minimizes the data load for analysis and transit, greatly reduces the time between inspection and action, and uses the network only for critical information that will add to the toolchain and drive greater insights and learning.

Who needs the intelligent edge?

The intelligent edge can benefit any business that manages infrastructure, networks, clouds, data centers, and connected endpoints such as sensors, actuators, and devices. It can support consumer use cases that require very low latency, like cloud gaming and augmented and virtual reality. It can enable enterprise uses that require aggregating, securing, and analyzing a great deal of data across operations and customers. And it can improve industrial processes for managing quality, materials, and energy use, such as monitoring factory floors, assembly lines, and logistics.

Not all businesses will be able to implement intelligent edge solutions broadly right away. Many may need to invest in the right infrastructure and partnerships first before seeing a return on investment from narrow use cases. But laying these foundations can give organizations much greater opportunities in the future.

What's driving demand?

In the year ahead, we anticipate that early growth will be led not only by large telecoms but by hyperscale service providers, content delivery network (CDN) providers, and technology companies as they both consume and sell intelligent edge solutions. Technology companies, while marketing intelligent edge components, appliances, and software layers to early adopters, may also seek to reinforce their own manufacturing and supply chains with

The intelligent edge can benefit any business that manages infrastructure, networks, clouds, data centers, and connected endpoints such as sensors, actuators, and devices.

intelligent edge capabilities. Similarly, telecoms, hyperscalers, and CDNs are not only making more capabilities available to their customers, but also expanding their own intelligent edge infrastructures to advance strategic initiatives. In the medium term, the use of intelligent edge beyond these early adopters will likely grow among manufacturing, logistics, and supply chain.

Most spending on edge computing and intelligence today comes from US telecoms and communication service providers (CSPs).⁵⁵ With more devices moving on and off networks, and with more diverse bandwidth needs emerging, these network providers are facing mounting management challenges. They are using intelligent edge technologies to transform and reinforce their own infrastructure, such as by expanding central offices to become next-generation data centers and edge hubs, enabling high-density and dynamic connectivity for 5G and multi-access edge computing (MEC),⁵⁶ and virtualizing more of their networks with solutions such as open RAN. These steps support their core business of delivering greater quality of service to subscribers and selling networks to enterprise customers.

Hyperscale cloud and service providers are also moving quickly to add intelligent edge capabilities to their data-driven businesses. Demand is growing from use-case driven solutions such as autonomous vehicles and mobile robotics that require low-latency, high-redundancy capabilities, as well as from manufacturing and supply chains seeking greater transparency and resilience in a post-COVID-19 world. Further demand may come from the intelligent edge's ability to address emerging regulations for data sovereignty and compliance. With an intelligent edge, data can be secured and held locally, keeping it within the region it was collected instead of sending it to foreign clouds.⁵⁷ This could potentially draw more investment from social media platforms looking to the intelligent edge to help them comply with regulatory regimes, such as the General Data Protection Regulation (GDPR), that may require personal information to be processed locally and anonymously.⁵⁸

Finally, rising demand from industries like manufacturing and mobility (such as automakers and ride-hailing services) could lead to the development of more packaged and managed offerings. This could make it easier for more businesses to attain intelligent edge capabilities. As the COVID-19 crisis accelerates migration to the cloud, businesses undergoing their first wave of cloud transformation could design cloud-to-edge solutions that best meets the needs of their use cases.⁵⁹

Who plays in the intelligent edge ecosystem?

No single provider seems able to build an effective intelligent edge solution by itself. Telecoms, hyperscalers, CDNs, and tech companies all play a role in enabling the intelligent edge, with each providing a part of the solution. Coordinating these various components is not easy: With each company pursuing its own strategic

goals, cooperation is often not far from competition. Understanding the role of these players, what they offer, and how they fit in the competitive landscape can better arm organizations looking to attain intelligent edge capabilities.

Telecoms and the expanding internet

For many intelligent edge deployments, telecoms are key partners,⁶⁰ with the largest telecoms increasingly selling their own edge computing and IoT solutions as well as on-premise private enterprise networks. As providers within the edge ecosystem, telecoms can offer their enterprise customers and partners end-to-end connectivity for wired and wireless networks, from fiber, cable, 4G/LTE, and Wi-Fi to advanced solutions with 5G and Wi-Fi 6. They also lease portions of their network that enable direct access to backhaul and offer real estate to host edge appliances and datacenters in central offices. Cell tower companies can also lease space for edge appliances at their towers, which typically connect directly to fiber.⁶¹

One key challenge for telecoms is that they no longer have a near-monopoly on connectivity and communication, despite the billions of dollars they spend each year to modernize their networks. Many CSPs deliver network services on top of IP networks, and more hyperscalers and CDNs are building their own network infrastructure. However, telecoms' ability to provide the combination of backhaul, 5G, Wi-Fi 6, and the intelligent edge could unleash stronger capabilities for managed connectivity, giving them a competitive advantage in delivering next-generation networks with greater quality of service.

Hyperscalers encircling the globe

Some of the world's most valuable companies—the so-called hyperscalers—offer end-to-end technology solutions,

from cloud services to enterprise productivity and consumer lifestyle experiences. These businesses are highly data-driven, both for optimizing and extending their internal operations, and to deliver better services and drive continued engagement by understanding their customers and users. They are implementing the intelligent edge to advance both efforts by extending their hyperscale capabilities closer to the things they measure, and the enterprises they serve.

Hyperscalers' biggest challenge will likely be to maintain control over data while partnering with connectivity providers. Hyperscale networks could indirectly encroach on CSPs, especially if they were to offer connectivity as a part of their platforms. Nevertheless, building high-quality networks is difficult and costly, especially at scale, which makes partnerships with connectivity providers a more feasible route.⁶²

As hyperscalers pursue intelligent edge deployments, they will establish new proofs of concept and use cases that will further drive adoption across the market. For example, some hyperscalers are positioning voice AI as a key interface modality across all their consumer services.⁶³ Being able to run natural language processing on the device—a smartphone, smart speaker, or car—without having to go back to the cloud can reduce latency, guard against connectivity failures and security breaches, and deliver greater quality of service while retaining data within regulatory jurisdictions.

For businesses deploying intelligent edge capabilities, hyperscalers offer public clouds and the IT services and management solutions that run on top of them, as well as AI capabilities. Some

hyperscalers already control their own CDNs as well. Their development and marketing of these intelligent edge solutions aim to support their expanding business offerings across cloud, payments, health care, transportation, and media and entertainment.

CDNs aspiring to become the other hyperscalers

Arguably, CDNs constitute a proto-edge in that they were developed to shift content closer to the consumer to accelerate the early Web.⁶⁴ Some CDN providers are now actively pursuing and marketing intelligent edge solutions, putting them in both cooperation and competition with telecoms and hyperscalers.⁶⁵

CDNs have strong relationships with many businesses, and they boast some of the industry's highest-quality, redundancy, security, and delivery capabilities. The intelligent edge may reinforce their delivery networks and enable greater quality of service at a time when more companies need strong delivery services. However, because some hyperscalers and telecoms already control their own CDNs, the sectors currently driving the intelligent edge may not need external CDN providers. Additionally, CDN companies may not have strong relationships with the industries likely to adopt edge next, such as manufacturing and automotive.

Tech providers offering hardware and managed services

Underneath the cloud-to-edge value chain reside innumerable hardware components and software layers that support it. Tech providers have a vast growth opportunity in selling their products and services into data centers, networks, on-premise facilities, and endpoints from factory floors and smart buildings to computers and vehicles.

Data center equipment and Wi-Fi connectivity will likely be in especially high demand. One forecast expects the edge data center market to approach US\$16 billion by 2025.⁶⁶ Tech providers can help telecoms transform their central offices into modern data centers, help manufacturing facilities build stronger on-premise capabilities, and provide intelligent edge appliances and micro-datacenters to enterprise customers. They can also offer the middleware and management layers that tie these hybrid clouds together into seamless fabrics. In this sense, the edge is another location for the hybrid cloud.

Also, not all intelligent edge solutions require 5G, and more solutions may develop hybrid networks that include Wi-Fi, LTE, and 5G, depending on the use case. This means that some tech businesses may see more opportunities as Wi-Fi providers. The latest generation of Wi-Fi, Wi-Fi 6, offers bandwidth slicing, better power management, and support for an increased number of devices,⁶⁷ all of which can enable much more robust and dynamic local networks. Private local networks could also help some businesses reduce their dependence on cloud providers and telecoms.

All this being said, tech providers' position in the intelligent edge marketplace may be challenged by some of their largest customers—the hyperscalers and telecoms—building more of their own components, as well as the ongoing trend to dematerialize hardware into software wherever possible. However, as the market matures, tech providers may also serve more second-tier adopters less able to build their own solutions. This shift may be the next milestone for the realization of Industry 4.0, in which next-generation cloud-to-edge architectures become more standardized and commoditized.

Don't forget semiconductors

Running AI on lightweight edge devices can require more specialized compute solutions such as custom field programmable gate arrays (FPGAs) and application-specific integrated circuits (ASICs), as well as GPUs designed specifically to accelerate AI algorithms on devices, in edge appliances, and in micro-data centers. Demand for edge AI chips has grown substantially, and the market will likely expand considerably in the next few years.⁶⁸ To meet this demand, more semiconductor companies are accelerating production of edge AI chips.⁶⁹ Some are pursuing monumental M&A deals to shore up their position in the next wave of machine intelligence and computation.⁷⁰ Hyperscalers are also designing more of their own specialized chips to support their largest operations. And foundries and chip design firms are responding to meet the demand driven by data centers, AI, and the ever-expanding digitization of industrial systems.

What are the potential headwinds?

As it matures, the intelligent edge market faces some challenges. The COVID-19 crisis has disrupted demand, challenged supply chains, dragged down earnings, raised costs for many businesses, and injected uncertainty into outlooks. Additionally, the ongoing trade war continues to drive supply uncertainty, adding complexity, cost, and time to navigating supplier networks. In this environment, demand is difficult to auger and supply may be unreliable. Such conditions may engender a more conservative approach to capex on emerging technologies. Businesses may feel they can reinforce their existing cloud capabilities with less risk than implementing an intelligent edge, especially during a crisis that is demanding more remote and connected services.⁷¹ Building the fundamentals

of cloud migration may occupy many businesses in the near term, leaving edge development to the largest providers.

Additionally, while edge opportunities are becoming clearer, many companies may still regard them as a forward-looking strategic investment rather than an obvious way to drive their current business. Implementation can be challenging and costly, often requiring orchestration between multiple providers. Standards are still forming, best practices are not yet clear, and security across an abundance of diverse edge endpoints cannot yet be guaranteed.⁷² In times of greater economic restraint, investments in the future may be easiest for the largest and

most durable businesses—and even they may need to orchestrate services across providers.

The year 2021 may thus see the intelligent edge colonized primarily by already-dominant tech sector and telecom leaders, further reinforcing their competitive advantage in the coming wave of transformation. The efforts of these early adopters over the next year can help the intelligent edge prove its value. In the next two years, the market will likely sort out best practices, establish standards and interoperability, and potentially lift early leaders while making it easier for smaller businesses to adopt intelligent edge capabilities.

The bottom line

Each party in the intelligent edge ecosystem—telecoms, hyperscalers, CDNs, tech providers and semiconductor makers—has a stake in the success of the intelligent edge and the next generation of cloud-to-edge architectures and services. The landscape is young and dynamic, but it also has decades of momentum behind it due to ongoing computing and network trends toward instrumentation, monitoring, and automation of facilities. With digitization, connectivity, and data analysis now maturing rapidly, the intelligent edge is beginning to transform some of the largest physical systems on the planet.

Like previous large-scale infrastructure upgrades, innumerable unexpected innovations will likely emerge as intelligent edge adoption expands. Executives should wade in and develop pilots with a clear path to results and strategic value. They should move beyond buzzwords and terminology to focus on use cases, metrics, and outcomes. Most importantly, they should understand that “edge” and “intelligence” are just components of a more holistic solution for faster data handling, greater autonomy and transparency across operations, and a more flexible and adaptive enterprise.

India perspective

The edge computing market in India is gaining momentum with the growth of drivers' in explosion of mobile data, driving telcos' need for low latency media processing, public cloud, IoT, AI, and big data. Players across the value chain, including telecom service providers, web scalers, technology companies and the start-ups ecosystem, are collaborating to bring together the segments of hardware, platform, and services to use on-the-edge computing opportunity. On the retail side, virtualization of work, a rise in consumption of high-definition videos, home automation, gaming, and increased usage of applications involving AR/VR, have created demand for truly immersive and digital experiences from customers. With the surge of data due to an increase in connected devices and rapid penetration of over-the-top (OTT), gaming, and e-commerce transactions in India, the demand would further extend to tier-2 and tier-3 cities. This requires the computing power of networks to reside as close to the consumer as possible.

Adoption of IoT, AI, and AR/VR in various vertical markets (including manufacturing, tele-medicine, video surveillance, logistics, and smart cities) is creating the need for ultra-high speed, low-latency intelligent processing. This would require cloud computing closer to where the data is generated. The IoT market in India was poised to reach US\$15 billion by 2020, accounting for nearly 5% of the global market.⁷³ As various verticals use IoT and cloud-based solutions to support their digital transformation, edge computing would become critical to support mission-critical use cases. Companies are also considering a multi-cloud approach that offers specialized capabilities to better align with the technical requirements and business-level objectives of particular workloads, applications, or services. IoT represents a sizeable opportunity

that would drive the edge computing market as technology providers, thus, transforming telcos into hybrid multi cloud service providers.

As 5G spectrum auctions are yet to take place, telecom service providers are looking for new revenue engines and exploring the opportunity to forge partnerships to enhance their offerings. This will help them realize returns on huge capital outlays to build and expand 4G networks.

Distributed multi-cloud strategy: Enhancing B2B and B2C offerings

Telcos have partnered with tech players and gearing makers to develop a distributed multi-cloud network strategy to build fully virtualized, scalable cloud architecture supporting connectivity, IoT, and fog and edge computing. Distributed multi-cloud environments would help address enterprise customers' needs related to cost, capacity, and performance and security.

Cloud transformation is aligned to telcos revamping their own network cloud, designing and integrating with IT cloud (to make it more cost efficient, flexible, and future-ready for core operations), enabling new digital services.

Edge data center co-location: Opportunity for infrastructure providers and hardware players

Even web scalers are seeing the need to process data closer to the source and telcos are proving to be suitable partners with licensing requirements for infrastructure deployment and already existing deep telco network connectivity. Telcos use their existing data centers to create edge data centers. With about 500,000 telecom towers in the country, infrastructure providers have the opportunity to transform legacy radio and transmission shelter

sites into edge computing-based micro data centers. With improved and steady power solutions, ready access to fibre backhaul connectivity, and requisite real estate, and Multi-access Edge Computing (MEC) could bring in customers, including Content Delivery Network (CDN) players, cloud providers, and telcos.

Platform business growth

Customers are shifting their focus to service-oriented consumption and delivery models. This shift is leading to collaboration between web scalers and technology companies with telcos to deliver a holistic platform-enabled edge cloud service capacity and performance metrics. Telcos are focused on monetizing their edge networks and experience delivered to customers on connected platforms. They are seen to focus on the platform segment, driving investments into the segment from large tech players. The collaboration promises to deliver enabled platforms, bringing intelligent cloud and edge across industry verticals. These verticals include media, digital commerce, financial services, gaming,

education, healthcare, agriculture, e-governance, and smart cities, supporting IoT, edge computing, and content delivery networks. This will also include providing benefits of network slicing to offer private service-defined networks supporting various applications and services of enterprise and retail customers.

Evolving start up ecosystem

Several start-ups are emerging in the edge computing space, providing niche solutions around hardware, products, platforms, edge IoT solutions, and services (including edge gateways, edge internet, edge platforms, AI and analytics). This is expected to further fuel the development of ecosystem. Recently, one of the leading telcos launched open architecture-based universal cloud. It is deploying the cloud across its edge data centers. The telco plans to open the platform to start-ups to drive innovation and co-create solutions that would enable start-ups to easily integrate and deliver edge computing services through the telco network.

The bottom line

The overall market in India for edge computing is in a relatively nascent stage and small compared with global markets. However, the expected growth rate for edge computing in the region (driven by IoT device management need and impending arrival of 5G) is likely to surpass global growth rate in the period 2020–27 with accelerated growth following the launch of 5G.

Telcos started their cloud journey to support their network and IT virtualization initiatives with impending arrival of 5G. With IoT growth, they see their critical role in the cloud value chain. The large traditional data center has been the mainstay of computing and connectivity networks to date. This will continue to expand in India across regions. However, the exponential rise in mobility and application services, coupled with digital transformation of enterprises, will propel service providers to increasingly add edge elements across the core, metro, and access networks. Following the growth of edge data centers, the hardware segment is likely to dominate the edge computing market in India, with the platform segment being a strong challenger as services evolve.

Edge computing's widespread application would be crucial for various reasons: to deploy content streaming services, smart assistants, AR/VR, Natural Language Processing (NLP), and speech recognition; to deliver immersive digital experience; or to ensure a 5G-ready cloud to support network slicing to create private networks (to support mission-critical IoT applications across manufacturing, logistics, smart cities, and vertical industries).

Collaboration across ecosystem players, including telcos, content delivery networks, tech providers, web scalers, and start-ups, to offer service-oriented consumption and delivery models (based on a holistic platform) to enterprise and retail customers would be key to success.



The next-generation radio access network

Open and virtualized RANs are the future of mobile networks

Mobile network operators (MNOs) are known for their ability to build and operate massive, high-performance wireless networks. They rely on highly specialized radio access and networking equipment with tightly integrated

proprietary software to deliver the cellular services that connect our cell phones, tablets, computers, and other devices. But high costs, limited flexibility, and constrained vendor choice are prompting MNOs to shift away from such

systems toward more open, standards-based, software-centric virtual platforms.

Many MNOs are well on the journey toward opening and virtualizing their core networks, achieving significant operational gains. They now have their sights on their distributed mobile edge networks: the radio access network (RAN). And because MNOs must replace or augment existing RAN equipment to deliver 5G service, they have the opportunity to adopt open and virtualized RAN architectures—which we will refer to simply as “open RAN”—as part of these deployments.

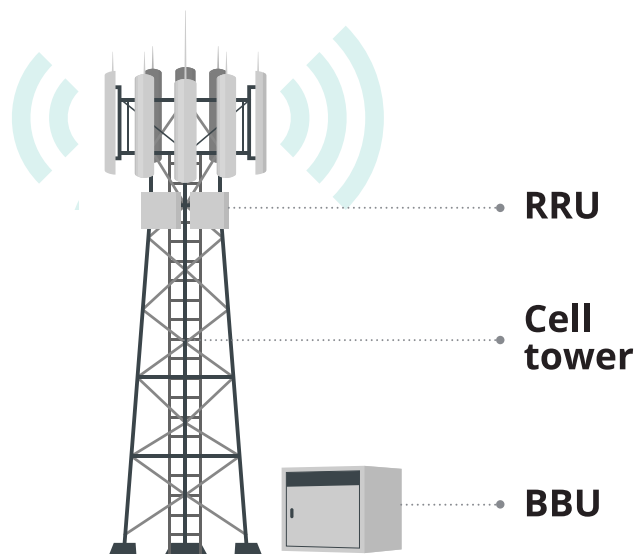
The open RAN market is still in its early days. We estimate that there are currently 35 active open RAN deployments across the globe,⁷⁴ many of which involve MNOs testing open RAN in greenfield, rural, and emerging markets. Although deployments are starting slowly, they could easily double in 2021. While it may take anywhere from three to five years for the technology to fully mature, open RAN adoption should accelerate rapidly thanks to the logic of its network design and its strategic alignment with carrier needs. Economic and competitive forces are also converging to drive the market forward. If this trend continues, the open RAN market has the potential to grow substantially, with some estimating double-digit growth rates⁷⁵ that will push open RAN to approach 10% of the total RAN market by 2025⁷⁶ from less than 1% today.⁷⁷ Moreover, if governments force MNOs to replace installed 5G RAN equipment from restricted vendors, the growth rate may be even higher.

Why open RAN?

At its most basic level, the RAN architecture at the mobile network edge comprises a remote radio unit (RRU or RU) at the top of a cell tower that communicates with a baseband unit (BBU) located at the tower's bottom. The RAN uses proprietary hardware and vendor-defined communication

interfaces, and its software-driven functionality is tightly integrated inside the hardware.

Figure 5: The traditional RAN architecture relies on specialized hardware and proprietary software, which raises costs, limits flexibility, and constrains vendor choice



Note: RRU = remote radio unit; BBU = baseband unit

Source: Deloitte analysis.

While these traditional systems have worked well for MNOs, they have many drawbacks. Making any upgrade or change to the wireless network, even seemingly minor ones, requires replacing physical hardware throughout the network—a costly, manual, and time-consuming process. Moreover, the proprietary nature of the equipment and interfaces that connect the hardware locks MNOs into existing relationships with the vendor that originally supplied them.

Virtualizing the RAN and replacing proprietary interfaces with standards-based interfaces enables equipment interoperability and multivendor RAN deployments. This gives network operators more flexibility to pick and choose among best-of-breed solution providers. By opening the market, currently dominated by a handful of vendors, to new suppliers, open RAN can not only lower costs but also prompt greater innovation through competition, as well as allow MNOs to avoid restricted vendors.⁷⁸ Additionally, because they allow operators to use software to push out network functions and intelligent automation, virtual architectures can speed the roll-out of new services that can help carriers better manage their networks, improving network performance.

Open RAN is not an entirely new idea; MNOs have discussed the concept of an open RAN architecture for decades. But despite open RAN's appeal, adoption has hitherto been slow and met with skepticism due to technical engineering and integration challenges. Substantial confusion over the terminology and available technology options has also hindered adoption.

Now, however, open RAN's momentum is growing as the ecosystem develops, partnerships form, suppliers ramp up investments, and operators commit to experimentation, trials, and deployments. Over the past several years, aggressive experimentation through both lab trials and live deployments are closing performance gaps between open and proprietary RAN solutions, steadily tearing down perceived barriers. Rising capital costs and national security concerns that further limit financial flexibility, as well as the rise of government policies to support vendor choice, are also accelerating the movement toward virtual and open RAN architectures. Finally, open RAN is riding the wave of several technology trends, including 5G, cloud virtualization,

distributed edge computing, and artificial intelligence (AI)-driven automation. All of these factors can help push open RAN from just a cool idea toward reality.

The taxonomy of virtual and open RANs

As is common with emerging technologies, the open RAN taxonomy is fluid. Evolving developments in engineering, configurations, and standards have led to conflicting terminology. Here, we will attempt to untangle the language needed to better discuss and understand the technology.

Open RAN encompasses two underlying concepts: virtualization and openness.

Virtual RAN decouples software-driven functionality from the underlying hardware, replacing purpose-built hardware with a programmable RAN infrastructure built with low-cost, general-purpose hardware. This allows operators to use a single virtualized BBU to support multiple radios instead of needing a proprietary physical BBU with fixed functionality at every cell site.⁷⁹ These virtual architectures facilitate the dynamic introduction and administration of software-based services at RAN edge networks without having to replace the underlying hardware.

Open RAN takes virtualization a step further. It not only disaggregates software applications from the underlying hardware infrastructure, but also replaces the proprietary communication interfaces between baseband components—the centralized unit (CU), the distributed unit (DU), and the radio units (RUs)—with open, standards-based interfaces. Open and standards-based interfaces enable operators to source the radio, baseband, and software from different vendors with plug-and-play interoperability.⁸⁰

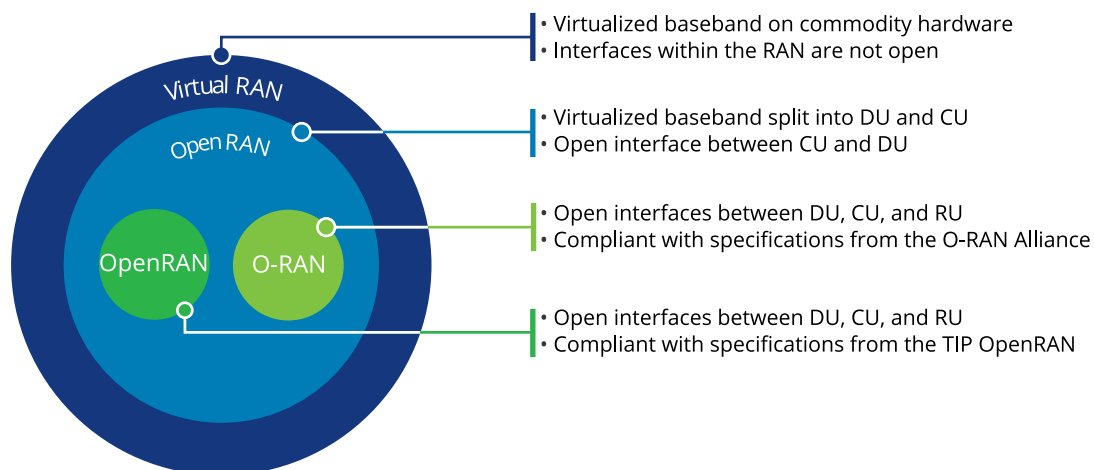
A RAN can be virtualized but not open. Virtualizing and opening RAN edge networks are separate decisions. An

operator can virtualize the RAN by disaggregating software functionality from the underlying RAN hardware and migrating to a cloud-native architecture *with or without* opening and standardizing the communication interfaces. For purposes of this article, however, we use the term “open RAN” to refer to a virtualized *and* open RAN architecture that gives MNOs both the flexibility to virtually manage RAN baseband components and the choice to source baseband hardware and software components from different vendors (figure 6).

Many would argue that virtualization is only a first but necessary step in the journey toward an eventual full opening. As long as the interfaces remain closed and controlled by the vendor, new entrants cannot participate.

Besides different degrees of openness, there are also multiple “flavors” of open RAN. For example, the O-RAN Alliance (with O-RAN) and the Telecom Infrastructure Project (with OpenRAN, not to be confused with our use of “open RAN”) promote specific standards-based open RAN reference architectures,

Figure 6: A RAN can be virtualized but not open



Note: CU = centralized unit, DU = distributed unit, RU = radio unit

Source: Deloitte analysis.

standards, and protocols that seek to foster vendor interoperability.

Multiple converging factors are driving open RAN adoption

Several main drivers—each, however, associated with a set of hurdles—are helping to accelerate Open RAN adoption

Virtual RAN architectures lower total cost of ownership

One of the most compelling value propositions of virtual RAN architectures, open or closed, is in their potential to lower the total cost of ownership of RAN networks. These cost reductions can derive from sources such as:

Lower upfront capital deployment costs. With rising capital intensity and slowing subscriber and revenue growth, MNOs view virtualized RAN as an important lever for fundamentally changing network economics. For instance, lowering capital costs is key to the optimal deployment of next-generation 5G wireless networks. 5G will require the addition of approximately three to four times more cell sites, albeit generally smaller cells on rooftops, lamp posts, and utility poles.⁸¹ Greater network density is needed to achieve 5G's promise for enhanced coverage, capacity, speed, and low latency, as well as to overcome the limited propagation characteristics of high-band spectrum. Estimates call for the addition of more than 2 million 5G cell sites in the United States by 2021, up from roughly 200,000 today.⁸² By allowing operators to aggregate baseband functionality using a single virtualized BBU to support multiple radios, open RAN reduces overall hardware cost and enables a smaller, simpler, and more energy-efficient installation footprint.

Virtual architectures can also “future-proof” investments in the physical network. Operators can use software to upgrade RAN features and functionality on the same physical infrastructure to keep pace with changing market conditions instead of having to rip out and replace whole physical systems.

Opening RAN architecture interfaces introduces vendor competition that can further reduce hardware costs. Open RAN allows operators to pick and choose among vendors—not just traditional telecom vendors, but big tech companies such as hardware manufacturers, web-scalers, original design manufacturers, and others looking to enter the market. The ability to change out individual RAN components with off-the-shelf hardware from any vendor can improve flexibility as well as reduce costs and downtime for system scaling and maintenance. That said, these savings from vendor choice are theoretical. Many

industry pundits argue that the additional cost, time, and effort to test and integrate multi-vendor systems could well offset, if not completely negate, any benefits from vendor diversity.⁸³ Additionally, the performance of processing-intensive RAN capabilities on general-purpose hardware may not match what can be achieved on bespoke optimized hardware platforms.

Lower operating expenses through automation. Open RAN has the potential to reduce ongoing network operating and maintenance expenses while simultaneously addressing the conflicting challenge of rising data traffic growth and customer expectations. Software-mediated RAN architectures empower operators with new levels of operational flexibility and intelligent automation that fundamentally shift how they manage networks.⁸⁴ Programmable RAN infrastructure also makes it simpler and more cost-effective to roll out new features and functions at distributed RAN locations at a mobile network's edge. Moreover, open interfaces enable these new network features and functions to operate on any vendor's hardware without having to send out engineers and technicians for vendor-specific integration, as is common practice today. Thus, open RAN could replace much of the time-consuming and manual work of maintaining, upgrading, and optimizing networks with light-touch, centrally managed, automated computing processes.

This type of automation, however, comes with its own challenges. To achieve these types of operational efficiencies, operators should become more adept in IT-style systems management and software engineering, imitating cloud service providers whose velocity in innovation showed the world how to drive value from network platforms. Operators must also adopt service-oriented practices using rapid-fire DevOps and continuous innovation and delivery (CI/CD) practices to deploy new applications with speed and precision—

something operators did not have to do with more traditional RAN deployments.⁸⁵

Not all operators are eager to take a more hands-on approach toward operations. For instance, anything that could interfere with network reliability is likely to give pause to MNO adoption.⁸⁶ To reduce this risk, some carriers prefer the ease and simplicity of traditional systems in which they rely on a few trusted vendors to provide new, fully tested, carrier-grade solutions with turnkey deployment, maintenance, and integration support. Should something go wrong, these operators can lean on their one vendor for remediation instead of having to identify and isolate the issue, then chase down the culprit from a pack of small, unproven vendors who may point the finger at anyone but themselves.

Open RAN encourages innovation

Beyond the capex and opex savings discussed above, open RAN also drives faster innovation. Instead of having to replace network gear to introduce new features and functions, MNOs using open RAN can use software updates on white-box gear to affect change, materially shortening upgrade and innovation cycles. Moreover, vendor interoperability negates the need to send out technicians for custom onsite integrations, further reducing the time, effort, and cost of launching new products and services.

Suppliers also benefit from open RAN because it opens up market participation and lowers barriers to entry. Because of interoperability, vendors can develop products and solutions for use by multiple operators instead of having to create unique one-offs for a specific operator. Interoperability also fosters best-of-breed solutions because vendors can focus on what they do best—whether hardware, software, or silicon—instead of having to develop an entire integrated end-to-end system.

Perhaps most importantly, open RAN systems enable MNOs to leverage

insights from the traffic flowing across their networks to develop solutions that improve network performance. Open interfaces encourage third-party development of AI/machine learning-driven solutions, which help operators deal with increasing array of bandwidth-intensive applications and the explosion of data flowing over ubiquitous networks and devices. Applications such as RAN intelligent controllers (RICs) and self-optimizing networks (SONs) are emerging as essential and cost-effective methods to manage future network complexity. The ultimate objective is to lower costs and achieve super-lean operations with zero-touch, fully automated end-to-end network management and service orchestration using AI-optimized closed-loop automation.⁸⁷

Open RAN innovation offers operators additional opportunities to evolve from merely providing commoditized “dumb pipe” connectivity to delivering differentiated customer experiences. For instance, MNOs might offer enterprise customers networks optimized for specific use cases. Examples of these could include ultra-reliable networks with near-real-time response for factory robotics or pervasive low-power wide area networks for widespread monitoring of assets such as gas pipelines or oil rigs. While it remains to be seen whether enterprises would take up, let alone pay for, these types of services, they do have the potential to open the enterprise market to operators—a market in which they have not been historically active.

While innovations made possible by open RAN could generate new revenue, it also introduces the risk of competition from new entrants. Although “coopetition” currently characterizes the competitive landscape, open RAN makes it easier for alternative players (web scalers, equipment vendors, system integrators, and so on) to capitalize on the greater availability of new low-cost wireless equipment to disrupt the mobile communications market. **Rakuten** and **DISH Networks**, for example,

plan to use open architectures to build low-cost alternative networks in direct competition with incumbent MNOs. And better access to lower-cost wireless equipment was the initial inspiration for **Facebook** to start the Telecom Infrastructure Project.

Open RAN drives greater vendor diversity and supply chain security

Consolidation over the years has concentrated the RAN vendor market to five major players: **Huawei, Ericsson, Nokia, ZTE, and Samsung**. Together, they account for more than 95% of the market, with the top three vendors, **Huawei, Ericsson, and Nokia**, controlling 80% of the market.⁸⁸

Market concentration has come to the forefront of political debate in the United States, where the government advisory and prohibition against using federal funds to purchase communications equipment or services from companies that pose a national security risk has restricted business with Chinese equipment manufacturers.⁸⁹ This effectively eliminates two of the five top vendors mentioned above (**Huawei** and **ZTE**) and highlights the degree of market concentration. Additionally, in April 2020, the US Department of State announced the 5G Clean Path initiative, which restricts the use of untrusted vendors in the transmission, control, computing, and storage equipment of all 5G mobile traffic entering or exiting American diplomatic systems at home or abroad.

The United States is not alone in making such moves. Multiple government initiatives around the globe are aiming to restrict the use of untrusted vendors. In July 2020, the United Kingdom announced that it would ban new purchases and require the complete removal of restricted kit from UK networks. And Australia, New Zealand, and Japan all effectively ban the use of untrusted

vendors from their 5G deployments. With more countries restricting vendors, the urgency for a new approach is driving greater worldwide interest in open RAN. To allow for alternatives, US policymakers increasingly seem to favor open RAN initiatives. They prefer the market development of alternative vendors to expand the supplier ecosystem that can give MNOs greater flexibility and choice.

For US MNOs, the lack of a US “national champion” equivalent to the largest players could become problematic if trade tensions escalate and national security is tied to homegrown network providers. However, even though it lacks a major integrated wireless equipment manufacturer, the United States is home to some of the most prominent emerging open RAN startups, including **AltioStar**, **Mavenir**, and **Parallel Networks**. Most of these suppliers offer open RAN networks compliant with the O-RAN architecture. Moreover, the United States boasts many of the most significant players in the hardware, silicon, and software supply chain ecosystem. These companies can partner with one another to cobble together an end-to-end carrier-grade open RAN solution.

The industry is uniting around open RAN

By opening the market and introducing competition, open RAN sets up a rift between traditional incumbents and forward-looking new entrants. Most of these new entrants, however, still need to establish themselves in the market; for now, the balance of power rests firmly in the camp of a few traditional vendors, which may, in fact, emerge stronger. Nonetheless, open RAN will force incumbent vendors to shift their business models away from a hardware to a more software-centric approach, introducing new business and competitive risks through the transition.

This tension is creating momentum for several industry-led open RAN initiatives that seek to unite an ecosystem of supply chain partners and advance open RAN through the definition, development, and testing of standards and reference architectures. Beyond the standards defined by the 3rd Generation Partnership Project (3GPP),⁹⁰ multiple industry groups are leading the open RAN movement, each with a different purpose. Prominent industry-led open RAN initiatives include:

O-RAN Alliance. This alliance, formed in early 2018, is a worldwide carrier-led effort that seeks to define new radio architectures. Its main objective is to open designs and interfaces between the RRU and BBU. It also focuses on vendor interoperability.

Telecom Infrastructure Project (TIP). Launched in early 2016 by Facebook, the TIP has more than 500 members and 12 project groups. Its OpenRAN project group focuses on building white-box baseband and radio unit designs based on O-RAN Alliance architecture and interfaces. TIP's primary goals are to develop an ecosystem to spur innovation, enable supplier diversity, and reduce deployment and maintenance costs across access, transport, and core networks.

Open RAN Policy Coalition. The Open RAN Policy Coalition, launched in mid-2020, advocates for government policies to help drive open RAN adoption. Its growing membership spans operators, equipment manufacturers, software developers, and silicon chip makers.

Open Networking Foundation (ONF).

In August 2020, the ONF announced several new initiatives in the open RAN domain. This group is looking to deliver open-source implementations of functionality included in open RAN components such as CU, DU, and RICs.

From a technical perspective, the O-RAN Alliance's work is the most foundational, prompting partnerships with many other organizations. The TIP announced a liaison agreement with the O-RAN Alliance in early 2020 that will allow the two groups to share information and hopefully prevent duplication of effort. In mid-2020, the telecom industry lobby group GSMA announced that it would partner with the O-RAN Alliance to accelerate the adoption of open RAN technologies.⁹¹ The ONF has also indicated it will work with the O-RAN Alliance to develop its solutions.

Like other aspects of open RAN, the roles of dependencies between and interactions across these groups can be confusing. And while well-intentioned, the plethora of initiatives has the potential to further fragment the industry, with each offering slightly different flavors of open RAN. To deliver a solution that universally appeals to multiple stakeholders, it will be critical for these various organizations to harmonize their efforts and provide a simple way for operators to learn about and embrace open RAN.

A sampling of open RAN vendor ecosystems

Companies big and small across the telecommunications ecosystem, including tier one and tier two operators, webscalers, traditional vendors, and startups from all corners of the industry, are beginning to coalesce around the open RAN model. Some of these players include:

Traditional RAN equipment vendors. These companies differ widely in the degree to which they embrace open RAN.

- Examples: Huawei, Ericsson, Nokia, Samsung, ZTE

New open RAN vendors. Several well-financed new companies are focusing on software-driven RAN architectures using plug-and-play, hardware-agnostic infrastructure to radically improve mobile network economics. These companies are slowly strengthening their reputation and positioning themselves to become key beneficiaries of the shift to open RAN.

- Examples: AltioStar, Mavenir, Parallel Network

Network hardware, software, and component providers. Many traditionally enterprise-focused hardware and component vendors are participating in open RAN industry initiatives to position their product portfolios to meet carriers' emerging needs. While most of these vendors do not offer radio technology, they are seeking partnerships in which they contribute software, hardware equipment, or components in efforts to engineer a complete integrated solution.

- Examples: Cisco, Fujitsu, IBM, NEC, Samsung, Hewlett Packard Enterprise (HPE), Dell Technologies, Lenovo

Chipset vendors: Each chipset vendor offers distinct solutions, with several providing accelerator kits to advance open RAN adoption. Sentiment is growing for the need for significant investment in 5G RAN silicon solutions to close the performance gap between restricted and unrestricted vendors.

- Examples: Intel, Qualcomm, Nvidia, Marvell, Xilinx

Cloud service providers: Cloud providers initially sought to offer MNOs cloud-based virtual environments to house and run internal applications and, eventually, external software-defined solutions. Now, webscalers and MNOs are increasingly partnering with each other to provide joint enterprise-oriented solutions for specific use cases, such as the need for low latency. With the emergence of new types of wholesale wireless arrangements from new entrants like **Rakuten** or **DISH**, webscalers and over-the-top media providers may emerge as formidable competitors to traditional mobile operators. They may even one day use open architectures to develop competing networks in their quest to connect the next billion consumers. It is this vision, coupled with frustration with the high cost of telecom equipment, that led Facebook to spearhead the TIP.

- Examples: Amazon Web Services, Microsoft, Google, IBM, Facebook

Barriers and challenges

Many challenges to open RAN adoption exist, many of which involve highly technical engineering issues that are beyond this chapter's scope. The following are some of the more commonly cited concerns that are

slowing open RAN's adoption among MNOs:

Carrier-grade scalability.

Experimentation with open RAN has thus far been largely limited to local and regional deployments. At a small scale,

open RAN's complexity of integration and its load on RAN network functions is readily managed. Several operators are experimenting with open RAN architectures in underserved areas where the potential for stranded investment and pressure for high performance is low and there is little or no existing infrastructure. In Turkey, for example, **Vodafone** is working with vendor partners using agile methods to make rapid iterative updates to software and equipment configurations, tracking KPIs to provide evidence of and confidence in achieving performance thresholds.

Whether this architecture is scalable to larger networks with greater traffic loads and higher performance requirements is still unproven. Still, some evidence of scalability comes from one of open RAN's few live deployments, undertaken by the Japanese e-commerce giant **Rakuten**. Rakuten is on track to deploy 7,000 open RAN sites in Japan by the end of 2021—the equivalent of a medium-sized European country such as Austria or Portugal.⁹² But as the number of subscribers on this network is relatively low, the technology's scalability to support tens of millions of subscribers is still in question.

Sunk costs. A traditional RAN's total cost of ownership, including the underlying equipment, site rental, support, maintenance, and energy costs, can be the most expensive part of a mobile network, representing 65–70% of its total cost. Given that, open RAN's appeal from a cost perspective is easy to understand. Several studies have concluded that open RAN can reduce capex by 40–50% and operating expenses by 30–40% relative to a traditional cellular setup.⁹³ Most of these studies cite **Rakuten**, which is striving to build the first and largest end-to-end virtualized cloud-native network using open RAN architectures.

The caveat is that while the total cost of ownership claims may be valid in greenfield environments such as in

Rakuten's effort, this magnitude of cost savings seems highly improbable in "brownfield" environments where significant investments have already been made. One of the main reasons for this is that 5G deployments build on and require interoperability with existing 4G infrastructure—and 4G's closed vendor implementations lock operators into using the same vendor. Accordingly, operators seeking to adopt open RAN in existing infrastructures would need to replace legacy equipment, which would significantly raise an open RAN deployment's overall cost.⁹⁴

Vendor interoperability concerns.

New solutions must compete against proven, tightly integrated legacy RAN systems designed and optimized for high performance. While open RAN provides greater vendor choice and flexibility in implementation, it also increases opportunities for incompatible configurations from multiple possible combinations of software and hardware. Each combination of multi-vendor end-to-end solutions must undergo extensive testing in a controlled environment, which would require significant additional time, effort, and cost relative to traditional setups.

To explore ways to alleviate this problem, several industry-led initiatives, including the O-RAN Alliance, are hosting "plugfest" events that bring together diverse ecosystems of component vendors to test, validate, and harden end-to-end operator solutions that can also interoperate with existing legacy architectures. Several leading vendors and consortia are also launching communal labs to test and validate interoperability in a controlled and managed environment.⁹⁵

System integration. Integration complexity also presents a significant obstacle to open RAN adoption, as one of the key benefits of remaining with the traditional model is that operators can turn complete responsibility

for implementation, upgrades, and maintenance over to the vendor. Should something go wrong—and it always does—accountability in the current environment is clear. If operators are to evolve away from reliance on integrated turnkey systems from a single vendor, they must incubate new capabilities to orchestrate and manage complex multi-vendor RAN deployments, which will necessitate the use of in-house, vendor-supplied, or third-party systems integrators. And since open RAN is a relatively new area, there are not many integrators with RAN experience that also have the operator's best interest in mind.

While anecdotal, **Rakuten's** experience again provides grounds for optimism. In assembling its greenfield mobile network, the company undertook a significant role as system integrator to orchestrate at least 10 different vendors, achieving many industry firsts in the process. Rakuten's CEO originally thought that the RAN integration would be the most complex part of coordinating these vendors. But he later acknowledged that although the RAN integration was extremely challenging, only 10% of the challenge came from the RAN and 90% came from "everything else."⁹⁶

Getting started with open RAN

Many operators are anxious to move forward with open RAN, and the market is developing rapidly. It may take some time, but many are confident the industry will eventually overcome the technical and engineering challenges that stand in the way of reaching a truly scalable commercial-grade solution. A mid-2020 survey of operators found that a majority believed that practical applications of 5G open RAN baseband units would emerge within two years.⁹⁷ The same study found that operators are not necessarily waiting

for full feature and performance parity. Many said that they would be willing to accept open radio units if they showed 80% of the performance capabilities of a traditional integrated system, particularly for service in underserved areas.⁹⁸

Even if open RAN is still not quite ready for widescale commercial deployment, this is no time to stand still. Since the telecom industry works on long multiyear planning cycles that can span decades, operators would benefit from taking action today. Now is a good time to assess the current state of their business, understand where the company needs to go, and determine how it needs to change.

Operators should start educating themselves on the opportunities and challenges presented by open RAN. A good place to begin is by separating hype from reality by participating in industry consortia, learning from those already testing open RAN in labs and field trials. Operators can also engage with vendors and other experts to understand global operator deployment trends, assess technology and ecosystem maturity, and evaluate the total cost of ownership of alternate deployments based on their own unique starting point.

While engineers tackle the technological issues, operators can take decisive action in developing an operationalization plan, building an organization and culture of innovation and continuous improvement to support new software-centric business and operating models enabled by open cloud-native architectures. If they want to successfully transition to open RAN, operators will need to acquire new capabilities, hire and develop internal talent, and adopt new ways of working.

Significant live open RAN implementations and trials

Rakuten, with its 7,000-site deployment planned for launch by the end of 2020, is leading the telecom industry's transformation toward open RAN architectures. Rakuten, which has a reputation for disruptive innovation, is leveraging the strengths of different vendors for various parts of the network, which has never been done before.⁹⁹ The lack of legacy infrastructure helps reduce the risk and cost of deployment.

Dish Network in the United States intends to build the first fully open RAN-compliant standalone nationwide 5G wireless network. The company is in the process of selecting the vendors that will help build the new, greenfield network. Dish plans to cover 70% of the US population with 5G by June 2023.¹⁰⁰

Vodafone is conducting extensive open RAN trials in the United Kingdom, South Africa, Mozambique, Turkey, Ireland, and the Democratic Republic of Congo with clear timelines for commercial deployments across multiple wireless technologies (2G, 3G, 4G, and 5G). The company is seeking to deploy open RAN technology across its considerable European footprint,¹⁰¹ which covers 100,000 cell sites and 400 million people across 14 countries.

Telefonica announced it will conduct 4G and 5G Open RAN technology trials in Germany, Spain, the United Kingdom, and Brazil in 2020. The Spanish operator will collaborate with several vendors to develop and deploy O-RAN trials across its footprint. Telefonica also has several open RAN projects in Peru.

Deutsche Telekom is collaborating with two vendors on developing a programmable open RAN platform based on a disaggregated open RAN architecture. The collaboration is part of Deutsche Telekom's European Open Test and Integration Center to test O-RAN compliant solutions.

Etisalat, a telecom services provider based in the United Arab Emirates, is launching the first Middle Eastern virtual RAN in collaboration with leading RAN technology vendors. Its solution seeks to decouple programmable RAN software elements from the hardware. This would allow generally available hardware and server platforms to process the RAN software, improving deployment flexibility, scalability, agility, and energy efficiency.

The bottom line

The traditional RAN represents one of the last bastions of closed proprietary systems. If history repeats itself, the adoption of open RAN may mimic the time it took the industry to transition to open and virtual core networks—the seven years between 2013, when the tenets underlying core network virtualization were introduced, and 2020, when more than half of the industry's core wireless shipments migrated from purpose-built to virtual network solutions. The expectation is that more than 80% of core wireless network deployments will be virtualized by 2023.¹⁰² Though open RAN is still in its infancy, the clear growing interest in the technology could be the start of a large and significant trend with the potential to revolutionize the telecom industry.

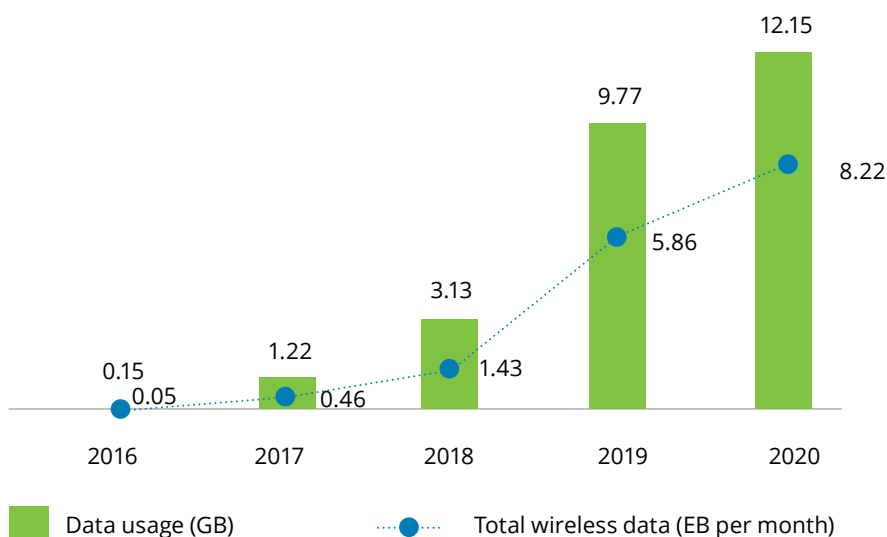
India perspective

Before we deep-dive into the future of open and virtualized Radio Access Network (RAN) in India, a quick preview of the Indian telecom market would indicate the following attributes:

Hyper usage: India had already reached the highest data consumption per user globally in 2019. This has only increased further in lieu of the black swan event of COVID-19 in 2020 (increasing the demand for seamless and high-speed connectivity). With the average wireless data consumption per user per month of 12.15 Gigabytes (GB), the country's wireless data consumption has reached about 8.2 Exabytes (EB) per month with a CAGR of 265.3% during 2016–20.¹⁰³

Frenzied capital intensity: Indian telcos have been investing in capex focused on 4G network expansion with an intensity (capital expenditure/sales ratio) of 40–50%, compared with the global average of 17–18%¹⁰⁴ in the past few years. The launch of 4G in the market with a pan-India reach meant service providers had to up their game in terms of technology, coverage, and performance (to remain competitive), and hyper data usage. While the investments were made, the organic revenue generation has not been sufficient to cover capital expenditure needs and service debts, resulting in additional funding requirements with a total industry debt of about US\$60 billion in FY20.¹⁰⁵

Figure 7: Wireless data consumption



Impending auction for 5G airwaves: 5G spectrum auction is now likely in 2021, delayed from the initial plan of auction in 2019. The delay is

largely attributed to the industry's financial health of the industry. The 5G roll out plan would require further investments by telcos in network densification and deep fiberization.

With the roll out of 5G network in the near future (to cater to the broadband boom in the country), Indian telecom service providers are channelising a majority of their investments on wireless and backbone infrastructure with projected spend in the range of US\$25–30 billion in the next 4–5 years.¹⁰⁶ Telcos are keen to invest in their 4G expansion that are interoperable with the future 5G deployments, and provide the benefits of quick scalability and optimization (using the network automation benefits of virtualized networks). According to some studies, significant cost savings to the tune of 40–50% of the capex and 25–35% opex savings (associated with deployment of Open RAN and overall traditional RAN), is another key driver for implementation.

Policy shifts involving restriction on certain equipment gears are bringing in procurement and supply chain uncertainties. These shifts could lead to increased dependence on existing gear manufacturers. Hence, major telecom service providers in the country that are already part of the industry alliances for Open RAN focus on extending their telecom gear supplier options to establish a new vendor ecosystem and cooperation for Open RAN adoption. Telcos are investing in creating the Indian stack to develop open and interoperable interface compliant architecture-based 5G solutions with a virtualized RAN by collaborating with design houses and manufacturers.

Expanding virtual and Open RAN deployments

Virtual RAN is essential for 5G, including mobile edge computing. Indian telcos are expanding their virtual and Open RAN footprint by deploying small cells and a massive Multiple-In Multiple-Out (MIMO) system across a dense location (as an overlay on its current 4G macro cell networks) and dis-aggregated solutions using Commercial off-the-shelf (COTS) equipment and capabilities aligned with the radio network requirements. Early adoption of Open RAN standards could prevent vendor lock-in during 5G.

Standardization of architecture

Regulators and policymakers, in conjunction with telecommunications standard development bodies, have initiated studies to develop cloud interoperability standards for India encompassing cloud for edge and Open RAN scenarios. Indian telcos are working with alliances, forums, and policymakers for standardization of the Open RAN standards and architectures that could facilitate quicker adoption.

Open source platform/software development

Tech players, gear makers, and telecom service providers in India are partnering to design Open RAN software to enable 4G and 5G radio network features and interoperability that would meet the most stringent requirements for a fully loaded site, including its requirements for availability, and network KPIs for enhanced customer experience (including throughput and handovers across technologies). With extensive benchmarking of performance in peak traffic scenarios and proven results, adoption across macro radio networks and urban/high-average revenue geographies is likely to be more widespread.

Integration and interoperability

To address the Open RAN integration challenges across hardware, software, platforms, and architecture, various players across the value chain (including telcos, gear makers, and software developers), are participating in plug-fests to perform integration testing and benchmarking against traditional solutions, and assess deployment readiness.

The first Open RAN plug-fest of the region was organized recently by one of the leading telcos. Players across the value chain participated in the plug-fest, demonstrating capabilities across Open RAN integration, network performance, dynamic network management, amongst others.

The bottom line

In the Indian context, fiberization of sites would be critical to make Open and virtual RAN architectures a reality and avoid performance limitations at a radio edge. Furthermore, the architecture's scalability to larger networks with greater traffic loads and higher-performance requirements would only be proven after extensive trials in the 5G environment.

Although Indian telcos have embarked on the Open RAN journey, they are likely to tread carefully to not shift their operations away from their tried-and-tested, traditional RAN partners, especially at a large scale. Open interfaces are likely to be focused on secondary or small cell networks and in underserved markets, especially for telecom service providers, delivering services up to fourth generation technologies.

The current network deployment and management model deployed by telcos gave the option to outsource end-to-end network services (across deployment and operation) with defined key performance indicators and service-level agreements to be delivered by vendors. The Open RAN architecture would require operators to continuously engage with various network vendors to integrate, optimize, and operate their networks. This could require telcos to build specific in-house capabilities to support new software-centric business and operating models.

In summary, the Open RAN ecosystem, technology, and standards are still evolving in India, with telcos focusing on deployment of Open RAN architecture to realize the cost benefits and performance efficiency. After the launch of 5G, adoption rates in India could accelerate rapidly and even surpass global numbers.

With huge investment outlays that lay ahead in building and expanding communication networks, many describe Open RAN as an economic imperative. Use of open standards and potential to source 'white box' for the radio network could be a game changer, providing financial feasibility, enabling telcos to expand their footprint (and 5G coverage in the future), and bringing digital India to every doorstep not just in cities but also in the remotest villages in India.





Video visits go viral

COVID-19 sparks new interest in video doctor's visits

Of all the activities that COVID-19 brought online, video doctor's visits may be the one that caused the most personal trepidation. After all, how can a doctor take your blood pressure, examine your throat, or evaluate a skin tumor over Zoom or Skype? But as it turns out, many consumers (and doctors) have been quick to change their minds about video visits' efficacy and appeal, and they are now prepared to do it that way for the long term.

We predict that the percentage of virtual video visits to doctors will rise to 5% globally in 2021, up from an estimated 1% in 2019.¹⁰⁷ While 5% may not sound like much, consider that 8.5 billion doctor's visits, worth a total of approximately US\$500 billion, took place in the Organisation for Economic Co-operation and Development (OECD) 36 countries in 2019 alone. 5% of that would translate into more than 400 million video visits and about US\$25 billion in

value, depending on how much doctors are paid (either directly by a patient, by insurance, or by national health insurance) for video visits compared to in-person ones.

The relationship of this growth to COVID-19 is clear. In April 2020, 43.5% of all US Medicare primary care visits were via telehealth; pre-pandemic, this figure stood at just 0.1%.¹⁰⁸ While telehealth also includes phone calls, emails, and non-video software solutions, the number of visits by video rose greatly. The number of people using the Department of Veteran's Affairs Video Connect system rose to 120,000 per week, compared to 10,000 per week in the same period in 2019.¹⁰⁹ Meanwhile, in the spring of 2020, video consultation services in France rose by 40–100%.¹¹⁰ And in a May 2020 survey, 14% of Canadians said they would choose a video doctor's visit where possible going forward.¹¹¹

More video and other types of virtual visits mean more business for the companies providing the technologies to support them. We predict that the market for pure-play telehealth virtual visit solutions will reach US\$8 billion in 2021.¹¹² Partially driven by the growth in virtual visits, we also expect that more than US\$33 billion of medical-grade home health care technology (mainly therapeutic and monitoring solutions, which can include medically approved consumer products such as smart watches) will be sold in 2021, up almost 20% over 2019.¹¹³

What happened?

The technology for video visits has been around for years. However, several factors—COVID-19 foremost among them—are converging today to drive higher growth.

COVID-19 left people no choice, and regulatory barriers were lowered

In March 2020 alone, authorities in the United Kingdom, United States, and Germany loosened regulatory barriers, modified rules around privacy, and endorsed telemedicine, including video visits.¹¹⁴ To quote one UK doctor: "We're basically witnessing 10 years of change in one week."¹¹⁵

COVID-19 also forced people to learn how to use the software. During the pandemic, literally hundreds of millions of people who had never used video calling software and hardware before used it for the first time as they worked from home during lockdowns. Even before the pandemic, video calling was relatively easy to use ... but many people hadn't. Postpandemic, almost everyone is now a veteran at setting it up, getting lighting levels right, muting and unmuting themselves, and so on.

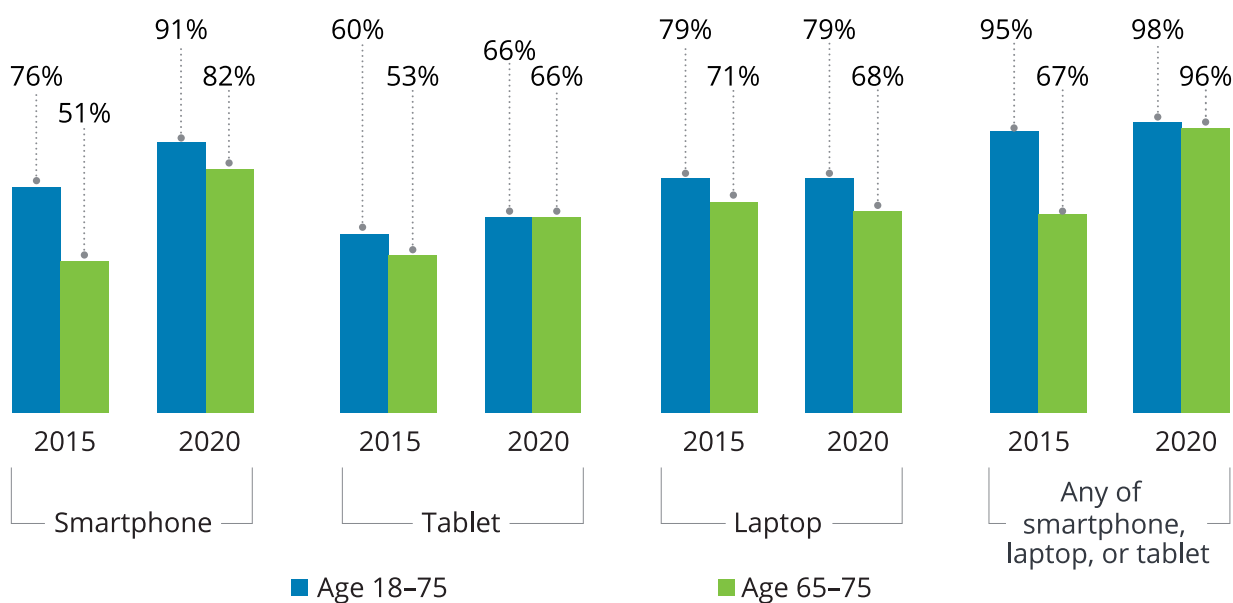
Importantly, the newly skilled at video calling includes tens of millions of people over age 65, who visit doctors more frequently than younger individuals. Although only 17% of the population, the 65-plus demographic accounts for more than 30% of all doctor's visits in the United States;¹¹⁶ in 2016, people age 65 and up made 80% more office visits than the average number of visits among the general US population. Historically, research has shown that elderly users, even when they have the right tools and connections, are still less likely to use digital applications, in part due to unfamiliarity.¹¹⁷ COVID-19 provided the impetus for them to change that. To stay in touch with children, grandchildren, and friends, the 65+ population underwent a rapid and forced training on video hardware and software. For them to be able to use it for virtual video visits with physicians is a fringe benefit that can drive substantial growth in the video visit market.

Devices and connections are reaching critical mass, especially among the elderly

The generational divide in digital device ownership has been rapidly narrowing in the last five years. As more older people become equipped to come online, their ability to engage in virtual visits will increase—an important consideration for those with limited mobility or other constraints that make it difficult to go to the doctor in person.

Historically, although the devices needed for video calls (laptops, smartphones, and tablets) have been broadly ubiquitous, their ownership has been much less widespread among those over 65. However, as figure 8 illustrates, this has begun to change. In 2015, one in three Britons age 65 to 75 did not own a device capable of supporting a medical video call. By 2020 that figure had fallen to 1 in 25 as more older adults bought tablets and especially smartphones.

Figure 8: The ownership generation gap is narrowing in the United Kingdom for devices other than laptops
UK device ownership by age



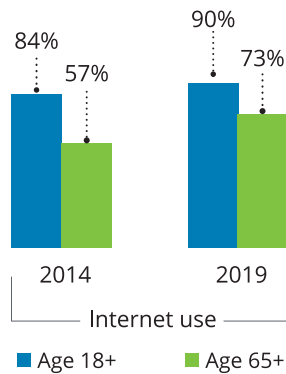
Sources: Deloitte UK Global Mobile Consumer Survey, 2015 and 2020 editions.

Of course, devices that are not connected are not useful, but here again the picture for those over 65 has markedly improved. In the five years between 2014 and 2019, overall internet usage in the United States rose six percentage points, but internet usage for people over 65 rose 16 percentage points. Although not

all senior Americans were connected in 2019, based on the growth rate in penetration and the pandemic likely over three out of four were by mid-2020, which is likely a critical mass for enabling widespread medical video visits among the 65-plus population.¹¹⁸

Figure 9: The internet generation gap is narrowing in the United States

US internet usage by age



Source: Pew Research Center, "Internet/ broadband fact sheet," 2019.

Connectivity's reach and speed are improving

Virtual visits' growth will depend partly on the extent to which more of the world's population becomes connected. As of 2017, about 12% of rural residents in the United States lacked access to fixed internet service of up to 10 megabits per second (Mbps) download and 1 Mbps upload.¹¹⁹ Furthermore, these speeds are maximum speeds: During periods of heavy use, when they are shared by multiple users in a home, speeds can be much slower. Most virtual video visit applications require at least 0.5 Mbps upload speeds, meaning that at times when connectivity is slower than the maximum for these users, their connections would not be able to support a video doctor's visit.

It is also worth noting that access to connectivity is lower among certain populations besides those in rural areas. "Digital exclusion" is higher for those living in social housing, from lower income groups, with visual and other disabilities, who are homeless or unemployed, who have lower levels of education and whose first language is not the country's native language(s).¹²⁰ Because of this, these populations will be slower to adopt of telemedicine in general and video visits specifically.

The connectivity situation, however, is slowly improving. Governments around the world, working with network operators, are trying to get more citizens connected to the internet, and at higher speeds, especially in rural areas. As telemedicine becomes increasingly important in delivering health care (once again, especially in rural areas), we can expect those initiatives to accelerate.¹²¹ It is also possible that low earth orbit satellite constellations may be able to provide high enough speeds for ubiquitous global coverage, though these networks are not yet in service, and many questions about them remain, especially around affordability.¹²²

5G will further accelerate telemedicine, as it allows for faster transmission of large image and high-quality video files, better augmented reality/virtual reality and spatial computing, and more reliable connections with guaranteed quality of service. In some cases, 5G could even allow telemedicine to move beyond diagnosis and monitoring, enabling doctors to perform actual procedures and surgeries using ultra-low-latency (under 10 millisecond) virtual technology.¹²³

COVID-19 may make video calling the default

Historically, most electronic communications for consumers and businesses have been email/messaging or voice-only calls, with video only used when absolutely required. Although we don't have hard data for how that may be changing now, we see signs that, as one commentator has observed, "Video calling is the new normal, and it's all because of coronavirus."¹²⁴ Some of video calling's appeal may be due to the medium's novelty, but if a preference for video over nonvideo methods is indeed rising, it has two critical implications for medical video visits. First, if we see a permanent shift to video over email and voice calls, then our prediction of 5% of all visits being video will likely be much too low. Second, video may make virtual visits much more medically effective.

Obviously, a video call helps a health professional assess a laceration or rash, but it also has the benefit of showing the patient's and health professional's faces. A seminal 1979 study, long before video calling was widespread, concluded that "Effective nonverbal communication—facial expression, voice tone, etc.—is essential for successful patient-practitioner interaction."¹²⁵

Sizing the global doctor visit market

Let's return to our prediction for the revenue generated by video doctor's visits. Why do we believe that video visits will be worth about US\$25 billion in 2021?

The market for physical visits with doctors is very large, but although there are some sources that give the number of annual visits for a given country, no single source tallying global visits exists.

Using two different approaches to size the market, we believe that patient visits to doctors (both physical and virtual) are likely to generate more than US\$700 billion globally in 2021. OECD member states will account for more than half a trillion dollars of this figure in 2021; if 5% of these are virtual, that works out to about US\$25 billion for video visits.

Methodology 1: Adding up per-country cost per visit

The OECD publishes data on annual per capita doctor consultations by country.¹²⁶ We multiplied the latest available data by each country's 2020 population to determine the number of annual doctor visits per country (Table 2). This analysis suggests that across the 36 OECD countries, with a total population of 1.31 billion people, more than 8.7 billion visits take place every year.

Table 2: More than 8.7 billion physical and virtual doctor's visits globally take place each year

Total number of annual doctor's visits by country, 2019 or latest available data

Country	Annual visits (millions)	Country	Annual visits (millions)
Japan	1594	Chile	73
United States	930	Portugal	71
South Korea	866	Slovak Republic	60
Germany	829	Austria	59
Turkey	801	Israel	54
Italy	411	Switzerland	37
France	385	Greece	34
Mexico	361	Sweden	27
Spain	341	Lithuania	27
United Kingdom	340	Ireland	25
Poland	288	Finland	24
Canada	253	Norway	24
Australia	199	Denmark	22
Netherlands	154	New Zealand	18
Hungary	103	Slovenia	14
Colombia	94	Latvia	11
Czech Republic	88	Estonia	7
Belgium	83	Luxembourg	4

Source: OECD health care data, with Deloitte research data for missing countries.

In some countries, patients, insurers, or both pay specific prices for doctor's visits. In other countries with state medical care, where the average patient pays nothing or very little, we assumed an average visit cost of what would be paid by a non-covered visitor for a 15-minute consultation with a general practitioner (GP). This cost number is almost certainly a minimum: Specialist visits would cost much more.

Based on a variety of sources for the 36 OECD countries, we believe the weighted average per-visit cost is about US\$61, although it varies widely between countries.¹²⁷ Multiplying each country's number of visits by the cost per visit for that country yields a total of about \$520 billion.

Methodology 2: Calculating visit revenue as a percentage of GDP

Our second methodology for estimating the market size for doctor's visits used the top-down approach of calculating doctor's visit revenue as a percentage of GDP.

The OECD 36 members' nominal GDP in 2018 was cumulatively US\$53 trillion.¹²⁸ In that same year, OECD members spent an average of 8.8% of their GDP on health care.¹²⁹ However, expenditure varies by country. Applying each country's health care expenditure percentage to its GDP yields a total health care spend of \$6.6 trillion across all 36 OECD countries.

OECD does have data for spending on general primary care (which excludes all hospital care as well as other primary care services such as dental, preventive, and home-based curative care), but only for 22 of the 36 countries, and only for 2016. For those countries and that year, general primary care (aka doctor's visits) represented an average of 6.8% of total health care spending.¹³⁰

Assuming that the rate is approximately at that level across all 36 countries, general primary care spending totaled approximately US\$450 billion for OECD members in 2016. If we include spending on specialist visits, it seems likely that total OECD spending on all doctor's visits was more than US\$500 billion, or more or less in line with the number produced using methodology 1.

Applying each country's health care expenditure percentage to its GDP yields a total health care spend of \$6.6 trillion across all 36 OECD countries.

Annual patient visit data also is available for some non-OECD countries. For example, in Brazil, the average person went to the doctor 2.8 times per year in 2017; with a population of over 212 million, that means that Brazilian doctors had nearly 600 million visits.¹³¹ Even assuming a cost of only US\$25 per visit, that would add another US\$15 billion to the total. And although we lack data for very large markets such as Russia, China, and India, at even one or two annual visits per person in these countries, the market would be billions of visits larger. In sum, the global market for doctor's visits could approach more than 12 billion visits per year, to the tune of US\$700 billion.

The bottom line

Although we do not expect video visits to stay at pandemic levels, they will almost certainly not return to the pre-pandemic rate of about 1%. Evidence suggests that many caregivers agree: A summer 2020 webinar survey of US health care professionals found that only 5% anticipated virtual visits to return to pre-pandemic levels.¹³²

One big reason that virtual visits are likely to persist is that patients like them. In a recent survey, nearly half of Americans said they prefer health care professionals who offer phone or web-conference-based consultations.¹³³ Virtual visits tend to be more efficient, reducing visit time by 20%.¹³⁴ They reduce the wait time for seeing a specialist (pre-COVID-19 studies show that median wait times for specialist consultations were down 50% in New York City and 75% in San Francisco following virtual consultations).¹³⁵ They eliminate the need to travel to and from a doctor's office. They are also seen as safer.¹³⁶ Further, having video visits offer value beyond just convenience will enhance adoption over time.

That said, there are still some patients who do not see video visits as equal to physical ones. In an April 2020 survey, 66% of respondents believe that a doctor or nurse needs to physically examine them to understand their health needs, and 56% don't think they get the same quality of care/value from a virtual visit as from an in-person visit.¹³⁷

More broadly, although many patients, health professionals, insurers, and regulators already like video visits, driving adoption higher than pandemic levels will require buy-in from not just some, but many or all of these stakeholders. Health care providers and the health care ecosystem have considered video visits and other kinds of virtual health as a substitutive channel for in-person care delivery. "Next reality" transformation requires capabilities to position video visits as an integral channel for care management and as a way to drive reduction in the total cost of care.

Doctors and medical professionals are still learning how to optimize video technology and their own behavior for new models of care. As just one example, health care professionals should adapt their learning and training to go from a bedside manner to a "webside" manner. They also should look strongly at more proactive care with wearable and "nearables" (smart objects: everyday items with small, wireless computing devices attached to them) and more ubiquitous team-based solutions that also support caregivers.

Whether insurers and governments continue to reimburse for virtual video visits will matter a great deal in markets where insurers play a key role. Historically, many insurers have not paid for virtual visits at the same rate (or at all) as in-person visits. Once again, however, COVID-19 has prompted the situation to change. Many US insurers and the US Center for Medicare and Medicaid Services (CMS) relaxed rules around virtual visit reimbursement due to the pandemic. According to one US analysis, only 0.2% of the medical claims filed in March 2019 were telehealth-related; in March 2020, that number had risen to 7.5%.¹³⁸ Two-thirds of health professionals surveyed in a pre-COVID-19 2020 survey said that "top accelerators [for virtual health adoption] included overcoming regulatory barriers such as licensing restrictions and restrictions on allowing for site-neutral payments, along with implementing payment methods that reward better health outcomes."¹³⁹

Investors and companies should expect higher levels of investment in areas related to virtual health, as well as merger and acquisition (M&A) activity. In the first two quarters of 2020, health innovation funding globally was up by 19% compared to the same period in 2019, reaching a new record of US\$9.1 billion.¹⁴⁰ And in August of 2020, two telemedicine industry leaders became one, as Teladoc spent US\$18.5 billion to purchase Livongo.¹⁴¹ Although they won't all be megadeals of that magnitude, more telemedicine M&A deals are probable.

The growth of video visits will likely have implications for other industries as well. The telecom industry, for instance, will have a large role to play in making virtual health care as widely available as possible. Although 90% of adult Americans and 73% of Americans over the age of 65 are connected to the internet, both numbers should be higher in order to make universal access to video visits possible. The numbers are roughly similar in other developed countries, but they are lower in developing countries and in rural areas globally.

In addition, sectors that produce technology that can be used for medical monitoring will likely benefit from video visits' growth. For instance, although smart watch sales declined to US\$25 billion in 2020, we anticipate that they will reach US\$64 billion by 2024, in part due to their use in medical applications.¹⁴² This in turn will drive change in the health care industry: Wearables such as smart watches have the potential to reduce hospital costs by 16% over the next five years.¹⁴³ But wearables also need to be used appropriately. As an example, the US Food and Drug Administration-approved Apple Watch wrist wearable device is a very useful tool for monitoring those who have been diagnosed with atrial fibrillation, but are much less useful at screening populations of presumed healthy people for the condition due to their high false positive rate.¹⁴⁴

No one today expects a doctor, black bag in hand, to make house calls. But thanks to video visits, it's now possible for patients to receive medical care at home once again. While video visits may never completely replace in-person consultations, we expect that over time, for those visits where they are appropriate, they will become as ordinary and acceptable an option as going to a doctor's office is today.

India perspective

Telehealth initiatives in India have been practiced since early 2000s. Historically, telehealth or telemedicine in the Indian scenario has largely been in the context of bridging the urban-rural divide in healthcare service delivery. Now with COVID-19, video consultations are becoming mainstream in urban markets. This is heralding the next phase of digitization in the healthcare sector where digital and technology investments to enable telehealth in urban markets could possibly provide an infrastructure boost for the healthcare sector at large, and improve the outreach and access in rural and remote areas. With the potential to fundamentally transform our approach toward healthcare service delivery, digital health initiatives taken now are likely to be the game changer for India in the next decade and bridge the urban-rural divide in healthcare to a greater extent.

The government expenditure in the healthcare sector in India was roughly 1.3% of the Gross Domestic Product (GDP) in 2016; the share increased to 1.6% in 2020.¹⁴⁵ The central government plans to increase healthcare spending to 2.5% of the GDP by 2025.¹⁴⁶ According to National Health Policy 2019, there are 25,778 government-run hospitals across the country, with 21,403 hospitals in rural areas and 4,375 in urban areas.¹⁴⁷ In contrast, the private sector accounts for 43,487 hospitals.¹⁴⁸ The Union Ministry of Health and Family Welfare stated that about 1.2 million allopathic doctors registered with the state and central medical councils, as of September 2019, across the country.¹⁴⁹ This translates into one physician per 10,189 patients against the one per thousand doctor-patient ratio recommended by WHO.¹⁵⁰

To summarize, roughly 70% of our 1.3 billion people live in rural and remote areas, while 75% of the doctors are in

cities and towns. Telemedicine as an approach was introduced in India in the early 2000s to bridge this gap and provide healthcare services digitally in remote areas. Broadly speaking, telehealth connects medical specialists in cities and towns with rural patients to diagnose and advise them on the treatment mode. The technology-driven service also helps rural patients avoid frequent trips to cities or towns, and save on the cost and time incurred on transport and stay.

Now with more than 700 million internet subscribers across the country (as of March 2020) and 696 million smartphone device users,¹⁵¹ internet penetration has increased phenomenally, even in rural areas. The period also brought in massive digitization and familiarity of digital technologies, and access across the board to the mass market, promoted by government initiatives (such as 'Digital India'). This sets the stage for large-scale technology adoption in high-impact sectors, such as education and healthcare. The pace of adoption has accelerated after the onset of COVID-19.

Over the past decade, digital health witnessed various innovations and developments, with pilot projects paving the way for their acceptability and subsequent growth. Cloud-based platform models were increasingly adopted to exchange and store information. They play a key role in enhancing telehealth services, improving performance, and increasing efficiency through high-speed technology, flexibility, and capability to store large amounts of data. Companies are also adopting AI and ML to analyze huge amounts of data and provide insights.

In these challenging times, the need to maintain physical distance and following other mandatory guidelines led to rapid growth of telehealth services

across the country, especially in urban areas. In a clinician's survey, about 80% respondents favourably responded to embrace teleconsultation.¹⁵² Raising income levels and demography, increased affordability, and a higher awareness toward health and wellness, coupled with growth of digital technology, higher penetration of internet connectivity, and favorable regulations are expected to drive the telemedicine market's growth. Investments in physical and cyber security infrastructure to ensure data privacy and protection will help support this growth.

Growth in digital healthcare is a significant step for a country like India where there are infrastructure bottlenecks in healthcare service delivery. Video consultations have the potential to unlock resources, including "time" for healthcare professionals. Non-critical and follow-up visits done remotely not only reduces the load on healthcare systems, but could also free-up time for healthcare professionals. This time can be efficiently used for critical care. For a country with a highly skewed doctor to patient ratio, digital and technology investments to enable telehealth could unlock critical healthcare resources and provide the infrastructure boost for the healthcare sector at large.

Another important outcome of digital health initiatives centering telehealth will be decoupling of "expertise" from "infrastructure". Hospitals will become infrastructure enablers with trained healthcare professionals who bring specialists and experts from across the world through partnerships with global institutions, to provide high-quality critical care. This will not only bring global expertise to India, but also become a significant forex earner (through healthcare service exports). Medical tourism is already an important segment in the healthcare industry. With digitization and telehealth becoming mainstream, there is a strong possibility

that export of healthcare services through digital channels become an industry in itself in the medium-to-long term.

Contemporaneous developments in medical diagnostics technology through low-cost consumer devices and mobile health applications, including wearable sensor-based medical devices and smartphone apps, can be used in this environment to provide efficient and quality care. By various estimates, the healthcare app market in India was valued at US\$370 million in 2018. It is estimated to reach US\$1.8 billion by 2024, growing at an estimated CAGR of ~32% during the 2019–24 period.¹⁵³ Advancements in technologies such as AI are further accelerating the digitization journey in domains such as medical imaging and diagnostics, through automated analysis of medical tests and predictive healthcare diagnosis through wearable devices. Taken together, advancements in consumer healthcare technology, along with the broader digitization of healthcare infrastructure through telehealth platforms, will herald the next phase of healthcare service delivery in India and across the world.

That said, the current telemedicine market is largely skewed toward urban areas, and Tier-2 and 3 cities are poised to outpace tier-1 cities in the adaption of preventive healthcare and technology. Telemedicine is at a fledgling state in rural India. Challenges such as low acceptance of computer or app-based tele-consultation, poor awareness of the benefits of telemedicine, and lack of guidance can be addressed by various measures. These measures include educating masses, provisioning e-clinics or mobile units, improving internet connectivity, and providing assisted service delivery. Assisted digital healthcare could become an important service delivery model in rural and semi-urban areas, where trained medical staff helps patients get access to healthcare

services through digital channels. Combined with low-cost diagnostic devices and solutions, this model could significantly bolster the capabilities in primary health centers (last mile delivery) and bring high-quality medical care closer to the doorstep of a larger population. Collaboration among the government, the private sector, digital health start-ups, and insurance companies, along with innovative pricing and commercial models, would be necessary to make this a reality.

Policy and regulatory scenarios

In March 2020, the Health and Family Welfare Ministry and NITI Aayog released guidelines on telemedicine.¹⁵⁴ Per the

guidelines under the Indian Medical Code Act, 1956, a Registered Medical Practitioner (RMP) is eligible to provide telemedicine consultation to patients located anywhere across the country, using any mode of communication such as video, audio, and text-based messaging/text-chat platforms. These guidelines permit doctors to provide teleconsultation to prescribe medicines, provide counselling (for instance, diet consultation, do's and don'ts for a patient on anti-cancer drugs, and proper use of hearing aid) and impart health education (advice on contagious infections, exercises, hygiene practices, mosquito control, etc.).

The bottom line

As a disruptor, telehealth is likely to be a game-changer in post COVID-19 India. It has the potential to revolutionize healthcare services in urban and rural areas and provide quality healthcare delivery. While the current telehealth initiatives are still largely urban centric, digital and technology investments to enable telehealth could provide an infrastructure boost for the healthcare sector. Investments in physical and digital infrastructure, including cybersecurity protections for data privacy and security, will help bridge the urban-rural divide and ensure everyone has access to quality healthcare.





The cloud migration forecast

Cloudy with a chance of clouds

Growth in cloud computing has been a megatrend over the last decade, with the market experiencing triple-digit annual growth as recently as 2015. Even though growth among the largest hyperscale public cloud providers had declined to

“only” 31% annually by the end of 2019, and this rate is projected to (slowly) decline further in 2020 and 2021 as the industry matures, growth in cloud continued to outpace that in many other sectors.

It would have not been surprising to see cloud spending go down a few points in 2020, given the spending reduction in multiple areas driven by the COVID-19 pandemic and the associated global recession. Instead, the cloud market has been remarkably resilient. By some metrics, growth was more or less flat in 2020; by some other ways of measuring growth, it increased faster than in 2019, even in the face of the steepest economic contraction in modern history. The likely reason: COVID-19, lockdowns, and work from anywhere (WFA) has increased demand, and we predict that revenue growth will remain at or above 2019 levels (that is, greater than 30%) for 2021 through 2025 as companies move to cloud to save money, become more agile, and drive innovation.

"We've seen two years of digital transformation in two months."

Microsoft CEO Satya Nadella,
April 2020¹⁵⁵

How do we know that cloud is growing?

Of course, cloud is not the only solution in play. When viewed at the total company level, very few systems will be only on-premise, only public cloud, or only private cloud. Most deployments will likely use a combination of a public cloud and a private environment that remain distinct entities but are bound together, an approach known as hybrid cloud. Hybrid cloud can take many forms, such as a combination of private with public cloud or public cloud with on-premise resources,¹⁵⁶ but all offer the benefits of multiple deployment models.

Clearly, hybrid cloud is the new normal. According to a March 2020 report, more than 90% of global enterprises will rely on hybrid cloud by 2022.¹⁵⁷ Another survey from the same month found that 97% of IT managers planned to distribute workloads across two or more clouds in order to maximize resilience, meet regulatory and compliance requirements, and leverage best-of-breed services from different providers.¹⁵⁸

But even though many organizations will retain at least some on-premise resources, and even in current economic conditions, cloud providers have much to look forward to as migration to the cloud accelerates. Various tangible and measurable indicators highlight the magnitude of this acceleration, including workload, revenues among public cloud providers, revenues among the semiconductor companies whose chips power the cloud, and growth in cloud traffic across global telecom networks.

As a note, many cloud forecasts are black boxes, based on proprietary information that cannot be replicated.¹⁵⁹ However, metrics such as hyperscale cloud revenues, data center chip revenues, and cloud traffic are all publicly available, and anyone can reproduce our work and see the same trends.

On-premise versus cloud workload

An April 2020 survey of 50 CIOs found that respondents expected to see the proportion of total workload done on-premise drop from 59% in 2019 to 35% in 2021, a reduction of 41%.¹⁶⁰ Moreover, they expected public cloud's proportion of total workload to grow from 23% to 55% in the same timeframe, with private and hybrid cloud reaching 20% and 7% of workload, respectively. 78% of the CIOs ranked "migrating to the public cloud and/or expanding private cloud" as the top IT spending driver in 2020, up 20 points from a similar survey only six months earlier.

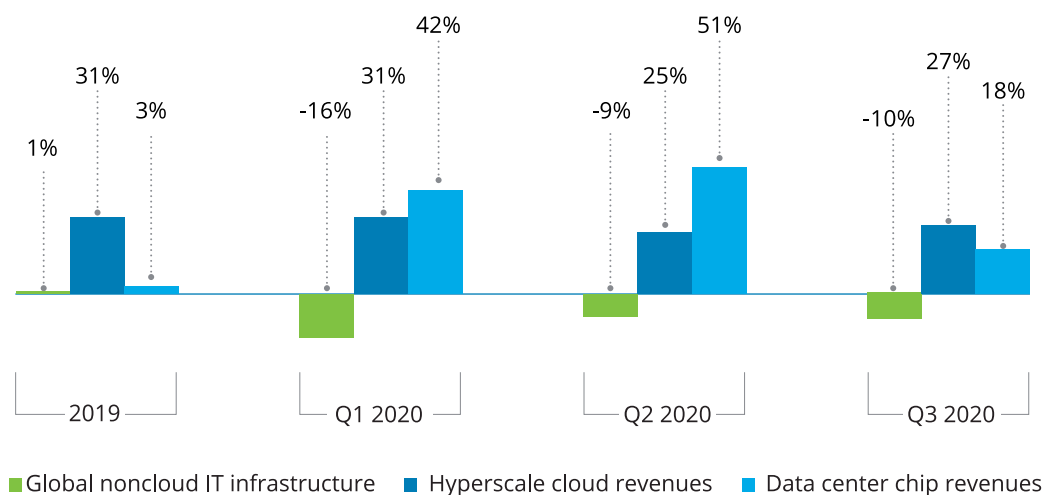
Hyperscale cloud revenues

The five largest hyperscale public cloud providers that disclose segmented revenues saw their combined revenues grow by 31% in 2019 to US\$94 billion. Despite widespread tech spending weakness in calendar Q1 2020, revenues grew by 31% over the same period in the previous year. In calendar Q2, growth showed a 25% year-over-year increase, which rose slightly to 27% in calendar Q3, resulting in a 28% growth rate over the first nine months of the year. Revenues for 2020 are likely to

be over US\$125 billion, increasing to more than US\$160 billion in 2021.¹⁶¹ And although percentage growth was down four points in the first nine months of 2020 compared to all of 2019, it is worth noting that in absolute dollar terms, the total hyperscale market (not just the five largest) grew more in 2020 than in 2019. The market in the first half of 2019 was about US\$40 billion larger than in the first half of 2018, while the market in the first half of 2020 was about US\$50 billion larger than in the first half of 2019.

Figure 10: Cloud spend has done better than overall IT spend

YoY growth in spend, percent



Source: Source: Deloitte analysis of quarterly and annual financial statements

Data center semiconductor revenues

As of mid-2020, there were 541 hyperscale data centers globally, with 26 added in the first half of 2020 and another 176 planned over the next few years.¹⁶² All of these data centers need chips. Though chip spending and cloud revenues are not perfectly correlated, they are connected in the long run, with growth in chip revenues usually being a leading indicator: The chips need to be bought and installed in the data centers before the cloud revenues start flowing.¹⁶³

The three largest semiconductor companies that disclose segmented data center sales saw their combined revenues grow by only 3% in 2019 to just under US\$30 billion. In calendar Q1 2020, they saw growth explode by 42% compared to the previous year. In calendar Q2, their revenues grew further to 51% year-over-year. Although growth declined to 18% in calendar Q3 this still works out to a 36% increase in the first nine months of 2020. Total 2020 revenues are likely to exceed US\$35 billion, and could top US\$40 billion in 2021.

Global cloud network traffic

According to a deep-packet inspection report on network traffic during the period from February 1 to April 19, 2020, global cloud traffic as a percentage of total internet traffic rose from 1.26% to 1.83%, up by 45%.¹⁶⁴ Over the same timeframe, overall internet traffic grew by 38%, meaning that cloud traffic, measured by the absolute number of bits per day, rose by almost exactly 100%.

More evidence of cloud growth

Only about 10 large public hyperscale cloud providers and chip companies break out their cloud revenues on a quarterly basis in detail. However, many other companies sell chips, storage, and connectivity solutions into the cloud space. Although these companies are not necessarily providing detailed quarterly numbers, their commentary has been in line with those that do release exact numbers. As just one example, Micron, a

supplier of storage for multiple markets, said in Q2 2020 that "Our cloud DRAM sales grew significantly quarter over quarter, with strong demand due to the work-from-home and e-learning economy and significant increases in e-commerce activity around the world."¹⁶⁵

Additionally, investors have been pumping funds into the cloud sector, with total assets in the three largest cloud exchange traded funds (ETFs) reaching US\$6 billion as of mid-August 2020, more than US\$2 billion more than at the start of the year. Not only were assets up, but so was performance, with the three cloud ETFs yielding an average year-to-date return of 47% as of October 30, compared to only 22% for the NASDAQ and 1% for the S&P 500.¹⁶⁶

Additionally, investors have been pumping funds into the cloud sector, with total assets in the three largest cloud exchange traded funds (ETFs) reaching US\$6 billion as of mid-August 2020, more than US\$2 billion more than at the start of the year.

All the COVID-19-driven interest in cloud is driving mergers and acquisitions as well. In just the first four months of 2020, the value of completed data center acquisitions, at US\$7.5 billion in only 28 deals, was greater than in all of 2019.¹⁶⁷

The caveat

Although cloud is growing rapidly overall, it serves multiple industries, many of which have cut spending sharply. This means that while overall growth is strong, it is not uniform. As stated by the industry publication *SiliconANGLE*: “Because the big cloud players ... are so large, they are exposed to industries that have been hard-hit by the pandemic. As a result, we see pockets of spending deceleration even at these companies.”¹⁶⁸

What happens next?

Although the growth in cloud in the first nine months of 2020 was very high, many forecasts expected it to slow to some extent in subsequent quarters. However, two factors suggest that this decline in growth could be less than expected. First, although lockdowns are unlikely to be as uniform as they were earlier in 2020, flareups in the pandemic and more-localized lockdowns are still driving WFA and cloud growth. Second, in the longer term, the WFA “forced experiment”¹⁶⁹ is being seen as a success by many workers and employers. As an example, Siemens is allowing employees to WFA, where feasible and reasonable, two to three days per week going forward; this policy applies to more than 140,000 employees at about 125 locations in 43 countries.¹⁷⁰ Continuing or growing WFA arrangements like this could strengthen ongoing demand for cloud.

As far as the industry landscape goes, many technology markets see significant concentration with one or two large companies accounting for almost all of the market, and cloud is no exception. The two largest hyperscale providers accounted for 78% of all revenues among the top five hyperscale providers in 2019, and the largest chip company accounted for 82% of total data center semiconductor revenue in the same year.¹⁷¹ At least so far, the effect of COVID-19 has not led to increasing concentration; indeed, the leading hyperscale providers’ market share declined slightly (by one to three

percentage points) during the pandemic-related surge in cloud growth. Longer-term, as growth returns to historical rates, it seems likely, based on the history of technology, that market concentration will increase again. Economies of scale usually matter, and while it isn’t necessarily “winner take all,” it may be “winner take most.”

The market for hyperscale cloud services might be shifting from a global market to a decoupled market split between China, served mainly by China-based providers, and the rest of the world (ROW), served primarily by US-owned hyperscale companies. Based on limited data, it appears that the Chinese cloud market grew faster than the ROW hyperscale market through September 2020, and we would predict that decoupling would continue, if not increase.¹⁷²

Finally, it is worth noting that in addition to the pandemic, the move to cloud has a long-running tailwind in terms of demand. Flexible consumption models, also known as “everything (or anything) as a service” or XaaS, have become an increasingly important strategic shift for enterprises across all industries. This market draws on more than just cloud, but cloud is a critical enabler. As of 2018, the XaaS market was nearly US\$94 billion, and a pre-COVID forecast predicted a five-year annual growth rate of 24%, resulting in a market of over \$340 billion by 2024.¹⁷³ COVID-19 likely will accelerate the growth in flexible consumption models, but even post-pandemic, those making this cloud-driven shift can see greater financial predictability, lower unit costs from aggregation, and enhanced customer relationships. Companies that have shifted their offerings to an XaaS model have already experienced considerable success with both consumers and investors, challenging conventional valuations and placing pressure on industry players that are retaining traditional business models such as perpetual licensing and long-term contracts.¹⁷⁴

The bottom line

Cloud providers can take several steps to support their continued growth.

First, to paraphrase Spider-Man, “With great growth comes great capital expenditures.” Higher-than-expected growth is good news, but to keep up with it, cloud providers will likely need to spend more on capex. In 2019, total hyperscale spending on capex (which includes both IT infrastructure and physical infrastructure spend) was over US\$120 billion.¹⁷⁵ Given the continued growth in revenues, it seems likely that hyperscale capex will continue to grow at double digits, reaching US\$150 billion by 2022. Additionally, investment isn’t needed just for capex. For cloud providers, artificial intelligence (AI) apps and dev tools are critical to attracting and maintaining enterprise customers and require investment or acquisition.¹⁷⁶

Also, as cloud moves from roughly one-third of enterprise workflow to roughly two-thirds, and that more quickly than expected, concerns around privacy and security urgently need to be addressed. As just one example, the health care industry, which has been among the fastest to shift to cloud during the pandemic, will likely increase its exposure to new vulnerabilities, especially if the migration is not done properly. As articulated by *Healthcare IT News*: “While cloud computing better optimizes the use of resources in health care, it also creates significant risks. This is especially true when cloud adoption happens faster than proper due diligence can be applied by information security personnel. This trend will persist well after the pandemic.”¹⁷⁷

One emerging development for hyperscale cloud providers is the intelligent edge. The intelligent edge places computing power, specifically AI computing power, not in centralized data centers but closer to the end user, typically less than 50 kilometers. The intelligent edge is not a replacement for enterprise and hyperscale cloud data centers, but a way to distribute tasks across the network to increase timeliness, connectivity, and security.¹⁷⁸ In the intelligent edge model, much of the data that used to always go to the data center doesn’t go there anymore, and hyperscale providers need to make sure this data finds its way back to centralized clouds for analysis and AI training—and ensure that they’re not cut out of access to this data. Another goal for cloud providers is to develop vertical-specific apps that must reside at the edge due to latency requirements and other factors. One way that hyperscalers can deal with both data transfer and app development is through partnerships.¹⁷⁹

For their part, cloud users should consider the following factors as they continue to migrate to cloud:

The cloud migration strategy. Cloud migration isn’t just about moving to the cloud; it entails a state of continuous reinvention if cloud is to reduce costs and create new opportunities. Pre-pandemic, cloud migration was already often complex. Even a single application could be tied to multiple business processes, affecting vendors, balance sheets, and regulatory compliance, and different stakeholders could have different motives and expectations from the migration. A simple process could often turn into a fog of conflicting goals, broken dependencies, and cost overruns. Postpandemic, all of these factors will be even more challenging. It is critical to “disrupt your market without interrupting your business” during the migration.¹⁸⁰

Cloud, security, and COVID-19. As noted above, increases in cloud usage mean increases in the cyber attack surface, making security more important than ever—especially given the growth in usage driven by COVID-19. In an April 2020 survey of security professionals, 94% believed that the pandemic increases the level of cyberthreat. Almost a quarter said that the increased threat is “critical and imminent.” Only 15% believed that the cyber threat will return to previous levels postpandemic, while five out of six believed that the new threat level is permanent.¹⁸¹

Cloud costs and benefits. As multiple enterprises shifted rapidly to cloud during the pandemic, some saw costs balloon. Some companies saw costs rise by 20% to 50% just from the increase in usage, even without adding in the cost of new applications or data.¹⁸² As organizations migrate, there is also a cost of duplication, with organizations paying for both cloud and legacy systems at the same time as well as the cost of synchronizing data between them.¹⁸³ Going forward, companies should think about cost planning (for instance, to take advantage of reserving instances at a discount), which can reduce expensive fixes due to rushed deployments. Cost governance systems can also help maintain control over expenses. To conduct a cost-benefit analysis, companies can use a cloud value calculator to evaluate the gaps between the current state and potential future opportunities. This can help optimize infrastructure, increase staff productivity, and enhance business value.¹⁸⁴

New opportunities for value. Moving to the cloud is not only allowing organizations to recover but positioning them to thrive postpandemic, increasing resilience and supporting business continuity at first, and then allowing them to do new things and offer new services. Going forward, cloud can support benefits including collaboration, automation, scale, innovation, and agility.¹⁸⁵ For example, with regard to innovation, two-thirds of respondents in a 2018 Deloitte survey said that cloud fully allowed them access to the newest technologies.¹⁸⁶ Another study showed that 93% of companies surveyed used the cloud for some or all of their AI needs, requiring less investment in infrastructure and expertise.¹⁸⁷

Thanks to COVID-19 driving enterprises toward cloud, the cloud market will likely emerge from the pandemic stronger than ever. Cloud providers and others in the ecosystem have the opportunity to capitalize on increased usage to grow and flourish, while cloud users can seek to explore new ways for cloud to create value. Already, cloud has become much more than an alternative computing approach; in the near future, it is poised to become standard operating procedure for all types of businesses.

Sustainably powering the cloud

Many pundits as well as organizations, such as the World Economic Forum¹⁸⁸ and the OECD,¹⁸⁹ have called for a “green reset” following COVID-19. In that regard, cloud computing can help, not hinder, progress toward a more sustainable future.

As recently as 2018, cloud computing companies were attracting criticism for their energy consumption, with some assigning them the epithet “energy hogs.” More recent articles, however, have pointed out that these concerns are unjust. Cloud computing output rose by 600% between 2010 and 2018, while its energy use rose only 6%.¹⁹⁰

Further, not only is cloud’s energy use growing more slowly than its computing output, but cloud computing often uses less energy than the noncloud alternative. On average, using the public cloud for office productivity applications emits about 6-7 kg of CO₂ per employee per year, while a nonvirtualized on-premise solution would be responsible for nearly 30 kg of CO₂ per employee per year.¹⁹¹ In the consumer world, as of 2019, viewing a two-hour Netflix movie consumed just over eight watt-hours of energy from Netflix and its distribution partners.¹⁹² This is a fraction of the energy needed to drive to a movie theater or even of taking public transit.

The key measure for measuring the environmental intensiveness of cloud computing is power usage effectiveness (PUE), in which great strides have been made. The average annual PUE for large data

centers has fallen by 36% over 13 years, from 2.5 in 2007 to 1.59 in 2020 (lower numbers are better). Hyperscale data centers do even better on the PUE scale, at around 1.1–1.2.¹⁹³ That said, this improvement has slowed in recent years, and both hyperscale cloud companies and chip companies are working hand in hand to keep power consumption as low as possible.

Two megatrends account for much of cloud computing's energy demands. The first is obvious: if overall use of the cloud doubles, then, all other things being equal, energy use doubles as well. The second is that AI is making up a higher and higher percentage of cloud computing. Between mid-2012 and 2018, the cloud computing resources used by state-of-the-art AI grew by 300,000 times.¹⁹⁴ Much of this can be attributed to the increasing use of a kind of AI called machine learning—more specifically, a subset of machine learning called deep learning. In the past decade, deep learning has become more widely used in the cloud, offering tremendous new functionality. But the way that deep learning has become more powerful is by using much larger data sets for training, which means more computation, which in turn results in greater energy use. According to one Canadian AI researcher, "The concern is that machine-learning algorithms in general are consuming more and more energy, using more data, [and] training for longer and longer."¹⁹⁵

Several avenues exist to keep cloud's rising energy needs under control:

Improving overall transistor efficiency. Over time, transistors keep getting smaller. Today, a state-of-the-art 10-nanometer (nm) semiconductor device fabrication node is about 20–30 times more power-efficient than a 90-nm node from fifteen years ago.¹⁹⁶ Over time, we expect data center chips to keep becoming still more efficient.

Moving to special AI chips. Initially, all AI computing took place on general-purpose central processing unit chips (CPUs.) Over time, more specialized AI-specific kinds of chips were put into data centers: graphics processing units (GPUs, used for both training and inference), field programmable gate arrays (FPGAs, mainly used for inference), and application-specific integrated circuits (ASICs, used for both training and inference.)¹⁹⁷ Although power efficiency varies by the exact chips and tasks, at a high level, GPUs are 10–100 times more efficient than CPUs at training and 1–10 times as efficient at inference; FPGAs are 10–100 times more efficient at inference; and ASICs are 100–1000 times more efficient at both training and inference.¹⁹⁸ As more of these AI-specific chips are deployed in data centers, data center efficiency will keep improving.

Improving special AI chips. Moving from CPUs to specialized AI chips improves AI power efficiency, but AI chip technology is not standing still either. As one example, the next-generation AI GPU Tesla T4 from Nvidia doubled the energy efficiency for inference AI compared to its predecessor, Tesla P4.¹⁹⁹

Moving some AI processing to the edge: At one time, almost all AI was performed on the cloud, as edge devices such as smartphones, cameras, sensors and robots lacked the onboard processing capacity for complex AI. By 2024, in contrast, more than 1.5 billion devices will have dedicated edge AI chips (called neural processing units, or NPUs) in them by 2023.²⁰⁰ These NPUs, mainly used for inference, will likely reduce the demand for energy over time: They tend to be more efficient than the chips in data centers, and they eliminate the need to send large data files up to the cloud, which consumes more energy. And not only are edge AI chips relatively efficient already, but they are progressing rapidly, with one company announcing that its current edge AI solution is 25 times more efficient than last year's model.²⁰¹



5G is not hazardous to your health

Busting the radiation risk myth

As 5G becomes more widespread, some have sounded alarm bells about its supposed health hazards. Two main concerns have been voiced, both related to the radiation associated with the technology. The most common perception is that 5G causes cancer. The second fear is that 5G-emitted radiation weakens the immune system, enabling COVID-19 to spread.

Both of these fears, in our view, are grossly overblown. We predict that in 2021, it is very unlikely that the radiation from 5G mobile networks and 5G phones will affect the health of any single individual, be it a 5G user, a user of any other generation of mobile phones, or any individual in the vicinity of a mobile network but not actually using a mobile device. There is no link between the

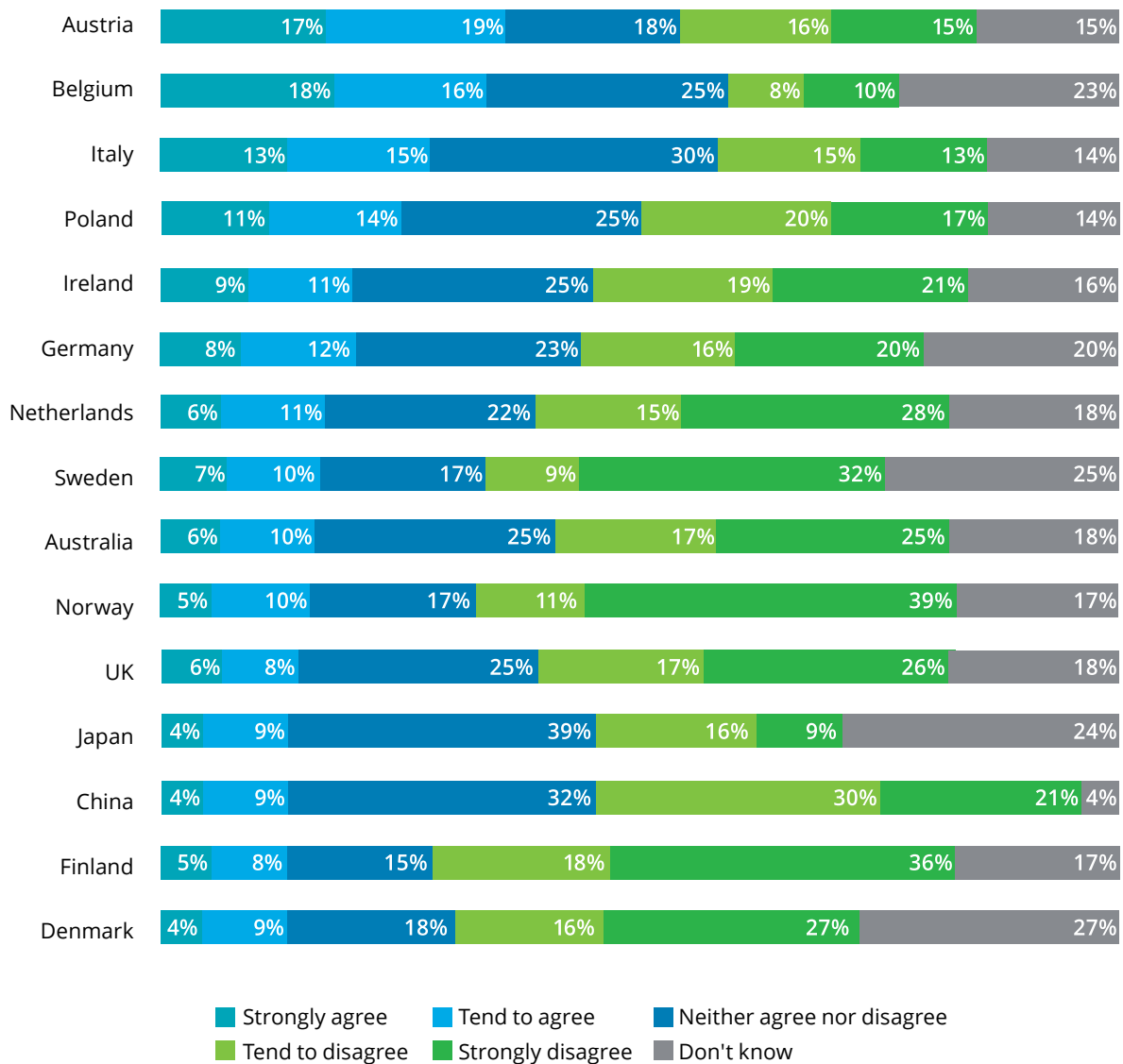
growth in COVID-19 infections and the roll-out of 5G networks.

Unfortunately, while extensive scientific evidence proves that mobile phone technologies have no adverse health impacts—not just for 5G but also earlier generations—we also predict that

between 10% and 20% adults in many advanced economies will mistakenly equate 5G with possible harm to their health. A Deloitte consumer poll in May 2020 found a fifth or more adults in 6 out of 14 countries surveyed agreed with the statement “I believe there are health risks associated with 5G” (figure 11).

Figure 11: A substantial proportion of consumers in advanced economies believe that 5G can be harmful to their health

Agreement with the statement: “I believe there are health risks associated with 5G” (by country)



Weighted base: Individuals age 16–75 who own a phone or smartphone in Australia (1,915), Austria (952), Belgium (1,909), China (1,953), Denmark (518), Finland (520), Germany (1,868), Italy (1,902), Ireland (948), Netherlands (1,953), Norway (475), Poland (1,909), Sweden (903), United Kingdom (3,841).

Source: Global edition, Deloitte Global Mobile Consumer Survey, May–July 2020.

Radiation ≠ radioactivity

What has led to this high level of concern about 5G's health impacts? It may have its roots in a simple confusion of terminology.

Radiation is commonly assumed to involve radioactivity, but this is not necessarily the case. The confusion arises because the words "radiation" and "radioactivity" have been conflated, a confusion that has persisted since the dropping of the Hiroshima and Nagasaki nuclear bombs in 1945. As a result of these events, as well as incidents at several nuclear power plants in the 75 years since, the term "radiation" has mistakenly become associated with destruction on a massive scale. In a similar vein, "radiation"—in reality, radioactivity—is also associated with cancer, reinforcing the word's connotation of mortal peril.

The point here is that radiation is *not* inherently radioactive. The literal definition of radiation is merely any process by which an object (from a human to a radiator to a star) emits energy (whether heat, light, or radioactive particles), which then travels through a medium (such as the air or hot water) and is absorbed by another object (a human body, a frying pan, a steam engine, or anything else). Radiation thus spans multiple everyday processes to which most people do not give a moment's consideration. In our daily lives, most of us are regularly exposed to multiple types of radiation, most commonly in the form of sunlight.

By this definition, 5G does generate radiation, but at very safe levels, and none of it is radioactive radiation. 5G base stations and phones, and the frequency ranges within which 5G operates, are very likely to be operating well within safe parameters in 2021 and throughout 5G's lifetime, which may extend to two decades. Radiation within these parameters does not significantly raise the risk of cancer. It also does not

weaken the immune system, and thus has not contributed to the spread of COVID-19.

Radio waves, 5G, and health: A new variation on a familiar theme

Understanding in more detail why 5G and other cellular mobile technologies are safe requires an elementary knowledge of how mobile networks and similar radio transmission-based services work.

Mobile phone networks are a variation on a conventional radio setup. A central transmitter relays sound via radio waves to a device equipped with an antenna (indeed, what is commonly referred to as "radio" today is a reference to the use of radio waves to distribute radio stations' content). Radio waves, are also known as radiofrequency electromagnetic fields (EMF), are a form of radiation, but a harmless one. Traditional television also uses the same distribution technique: A central transmitter relays sounds and images that are then received by antennas.

Today, billions of people receive TV and radio content via a network of transmitters that connect with receivers in homes, offices, and vehicles around the world. Although the proportion of video content delivered on demand has steadily risen over the past decade, most of the hours of video consumed globally are still likely to be transmitted wirelessly via national networks of transmission towers.

All generations of mobile phone technology, including 5G, take the same familiar underlying approach. A mobile network consists of a nationwide grid of cell sites. These sites feature transmitters that generate radio waves, which are received by a mobile phone's antenna.

The radio waves generated by mobile networks, TV stations, and radio stations are innocuous. On the very broad spectrum (known as the electromagnetic spectrum) in which radiation exists,

radio waves fall on the low-frequency, very low-energy end. Such radiation is sometimes referred to as non-ionizing radiation. This contrasts with radiation such as X-rays, gamma rays, and some types of ultraviolet light, which fall into the high-frequency, very high-energy end (figure 12). These types of radiation are referred to as ionizing radiation, so called because it has sufficient energy to damage DNA by removing electrons from atoms, potentially leading to cancer.

Admittedly, one difference between broadcast radio and TV and mobile telephony is that the receiving device can also transmit. But even this capability is not wholly new. Walkie-talkies were first used in the 1940s; mobile phone networks, though designed to be scalable to whole countries and used for person-to-person calls, work on the same principle.

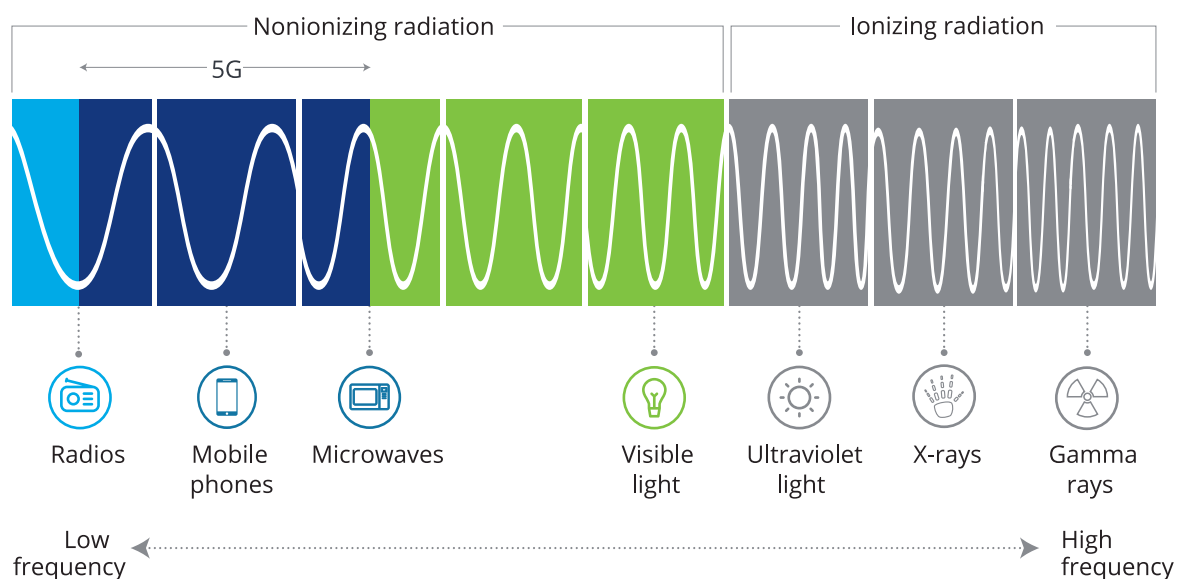
Another minor variation is the reach of each transmitter. For television, most transmitters in use today have a range of 65 to 90 kilometers.²⁰² For FM radio, the

range is likely to be up to 45 kilometers.²⁰³

Mobile phone tower transmitters, in contrast, typically have a range of between 50 meters and 20 kilometers, with the majority being low-range transmitters of less than 500 meters. The average range per base station has generally decreased over time as the number of base stations has increased, with the majority of additional base stations covering much less territory. With the rollout of 5G networks, cell size may be as little as 10 meters in radius (known as small cells), with a transmission power of 100 milliwatts.²⁰⁴ (The rationale for reducing cell size is to enable higher performance with regard to download speeds or the number of users per square kilometer.) With small cells, the base stations are small enough to be wall-mountable or attached to lampposts.²⁰⁵ As cell size decreases, transmission power required declines.

The reason for mentioning these similarities is to point out that mobile telephony, including the latest 5G standard, relies on the same underlying

Figure 12: The radio waves generated by 5G fall on the low end of the electromagnetic spectrum



Source: Adapted from SCAMP/Imperial College London/EBU.

transmission methods that have been used for decades. Content is created, relayed over radio waves, and received—a technique that has been delivering content wirelessly for more than 100 years.

Like the technology itself, concerns about the health effects of wireless transmission are not new. Some individuals were concerned about the impacts of earlier mobile network generations as well as of other types of wireless network, principally Wi-Fi and TETRA (a type of private radio communications network often used by emergency services). Looking further back still, some people worried about the health impacts of emissions from television transmitters too.²⁰⁶

A common concern going back decades has been the risk of brain and skin cancer from mobile phones. However, this concern has been demonstrated to be unproven. A 2019 study of mobile phone use and the incidence of brain tumors in Australia found no increase in the incidence of brain tumours since the 1980s. The researchers looked at the periods 1982–1992, 1993–2002, and 2003–2013,²⁰⁷ which covered the introduction of analog cellular (1G), 2G, 3G, and the beginning of 4G. Their conclusion: “[There have been] no increases in any brain tumour types, including glioma and glioblastoma, during the period of substantial mobile phone use from 2003 to 2013.” As for skin cancer, a 2018 review of medical studies undertaken between 1995 and 2017 found that “overall evaluations showed that the effects of mobile phone radiation on skin diseases are weak and have no statistical significance.”²⁰⁸ These skin cancer study alone comprised data from 392,119 individuals—a very large sample size.

What has been different about 5G is that the means of amplifying misunderstandings about its health impacts, either deliberately or ignorantly,

are greater than ever, because the capability to share true or false information is greater than ever before. Many individuals who believe 5G may cause them harm have had these ideas suggested to them, most typically via social networks, in sensational but plausible language.

Extremely low power, extremely low risk

Of course, non-ionizing radiation is not *always* completely harmless. The most common form of non-ionizing radiation is visible light, which has a higher energy level than radio waves. An excess of visible light—or even radio waves—can produce heat, and in extreme cases cause burns and body tissue damage. However, the power behind the radiofrequency radiation generated by mobile networks is controlled and poses virtually no risk to consumers.

Power transmission from mobile telephony, including 5G, is far lower than that from light bulbs, TV, radio towers, or even sunlight on an overcast day. The quantity of this power is measured in watts, and a single watt is a *tiny* quantity of energy. The power transmitted by the mobile phones used in 2021 and into the foreseeable future can reach up to two watts, depending on the age of the phone; it can be as low as 0.001 watt, with the vast majority of devices in use this year peaking at 1 watt. By comparison, the power transmitted by CB radios, which have been in use for decades, reaches up to four watts.²⁰⁹

As with a car journey, the shorter the distance, the less the power required. A phone held next to the head or kept in a pocket would have the greatest impact. The radiation level from a phone or speaker placed on a table near the user would be lower. A smartphone will transmit more power when base stations are relatively distant, but most smartphones are used predominantly indoors, and tend to be connected to Wi-Fi routers (which are effectively

miniature base stations), which are often mere meters away. In all of these cases, the amount of power transmitted is minimal—certainly much lower than required to be harmful. Further, a smartphone transmits power only when sending or receiving data, a mechanism designed to prolong battery life.

The power generated by mobile network base stations is similarly low. A base station's transmissions range in power from a quarter of a watt for a small cell (which would often be indoors and cover a small range) to 200 watts²¹⁰ for a minority of 5G base stations.²¹¹ More typically, an outdoor base station with the greatest range would have a power output of between 10 and 100 watts. The output of indoor base stations, which usually have a range of hundreds of meters or less, is much lower.²¹²

As with a phone, a base station's power level declines with distance from its transmitter. An individual 100 meters away from a 5G macrocell antenna located at 30 meters' height would absorb less than one microwatt (one thousandth of a watt) of power.²¹³ When one is directly next to a base station supporting any generation of mobile standard (not just 5G), exposure limits may be exceeded.²¹⁴ But these areas are inaccessible to the public, sometimes because of their height (20 meters or higher for larger sites), their location (often at the top of buildings), or their design (because the units are enclosed). In the case of indoor base stations, excessive exposure would only happen within a few centimeters of the transmitter.

Average broadcast transmission power has declined as the number of base stations deployed has increased, resulting in a smaller distance between base stations and users. Transmitter power levels for 1G and 2G networks were far more powerful, on average, than those used for 4G or 5G, since 1G and 2G transmitters covered a far greater range,

often tens of kilometers in each direction. In contrast, 4G and 5G masts in city centers and other traditionally congested areas may cover just 100 meters.

It is worth reiterating how minuscule a watt is. An incandescent bulb, which radiates light via a wire filament that is heated until it glows, is rated between 25 to 200 watts. In domestic settings, people may be less than half a meter away from a light bulb. A person this distance from a 25-watt bulb would be exposed to thousands of times more radiation than an individual who was 10 meters (unusually close) to a relatively high-powered 5G base station.²¹⁵ This is not just the case in 2021—it should hold true always. Similarly, people absorb five times more radio frequency exposure from FM radio and television broadcasts than from mobile network base stations.²¹⁶ The broadcaster transmitter power levels used for TV and FM radio can reach up to 100,000 watts.²¹⁷ For AM radio, the transmission power may reach 500,000 watts.²¹⁸

Humans have coexisted with incandescent light bulbs, and their radiation, since the 1880s with no known malign effects (except, of course, from being burnt from touching a lit bulb). As for broadcast power, the first television station went on the air in 1928,²¹⁹ and the first commercial radio station launched in 1920²²⁰—yet no reliable account of people being harmed by the radiation these stations generate has ever been reported.

5G is even safer than previous mobile network generations

In 2021, consumers who are concerned about the health impacts of mobile networks are likely to be most worried about 5G, the latest generation of mobile technology. However, in some ways, 5G is likely to have even lower potential health impacts than earlier generations of mobile telephony.

5G has been designed to use less power

than previous generations to reduce operational costs; as a result, it emits less power as well. This is accomplished via the new, advanced radio and core architecture used in the 5G standard, with 5G networks assisting 5G devices in minimizing power transmit levels.²²¹ 5G base stations also can be put into sleep mode when there are no active users (for example, at night). This capability is not available with 4G networks, which transmit control signals even when there are no users in range.²²²

5G also incorporates a technique known as beamforming, an approach that involves directing a narrow beam of radio waves to the user device (such as a smartphone). This method is equivalent to directing a narrow beam of light from a pocket flashlight at a target, focusing the radio waves on the device. This method not only enables higher connection speeds, but also leads to lower radio wave exposure than prior network generations,²²³ which would often spread radio waves across a wide arc, similar to a car's headlight.

Some people may conflate the risks associated with beamforming with industrial-grade laser beams. A manufacturing-grade laser beam, which is 100 million times as powerful as a typical laser pointer, is capable of melting steel.²²⁴ But beamforming in 5G networks involves innocuous levels of power.

As a final note, tests of 5G sites in 2020 by regulators such as Ofcom in the United Kingdom have found that their EMF levels are well within International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines.²²⁵ ICNIRP is an independent scientific commission based in Germany that works with the World Health Organization (WHO), the International Labour Organization (ILO), and the European Commission. The highest EMF level recorded among

the 22 locations tested was 1.5% of the acceptable level—in other words, 98.5% below the acceptable level. Most of the sites tested supported four generations of mobile technology; that is, a combination of 2G, 3G, 4G, and 5G (in many markets, 5G-only base stations remain relatively rare). At all of these sites, 5G contributed the least to the EMF fields measured. In 19 of the 22 locations, the highest 5G band value was less than 0.01% of the acceptable ICNIRP level.

5G and the spread of COVID-19

One myth about 5G's impact on health that has been widely spread in 2020 is the fictional association between the roll-out of 5G and the spread of COVID-19.²²⁶ Put plainly, the idea that 5G transmits COVID-19 is as bogus as it is impossible. COVID-19 is a virus spread through respiratory droplets from other people. A virus does not travel via radio waves.

A variant of 5G misinformation related to COVID-19 is that 5G emits radiation that weakens people's immune systems, making them more susceptible to illness.²²⁷ This is similarly false.

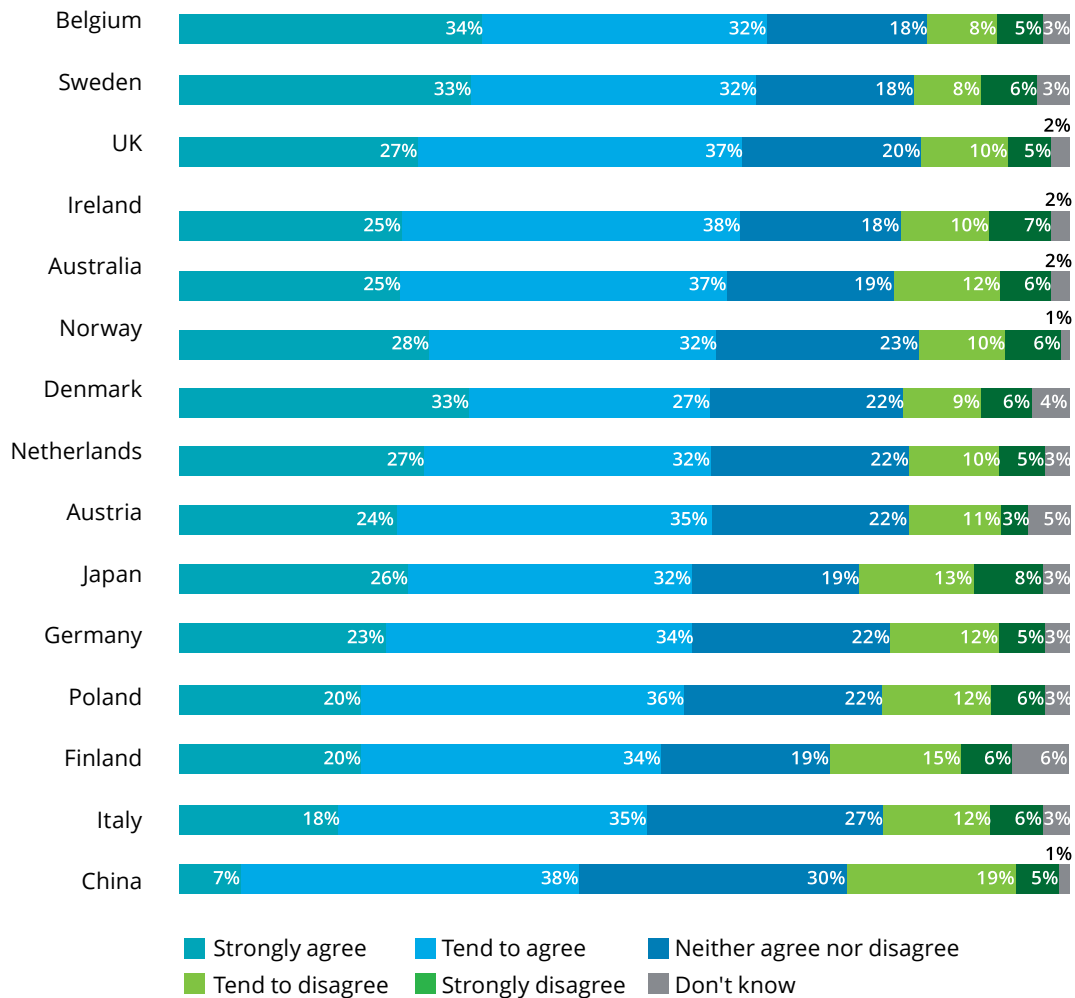
It is likely that misinformation about 5G's relationship to COVID-19 will be as pervasive in 2021 as it was in 2020. An Ofcom survey at the end of June 2020 found that 29% of respondents had come across false or misleading information about COVID-19 in the prior week.²²⁸ The most common topic, seen by 21% of respondents, was "theories linking the origins or causes of COVID-19 to 5G technology." Misinformation about 5G was even more prevalent earlier in the year: An Ofcom survey undertaken from 10–12 April 2020 found that 50% of respondents had seen false or misleading statements about 5G. The good news is that these people recognised the misinformation as such.²²⁹ The bad news is that the majority (57%) of those who saw what they regarded as misinformation did nothing about it.

The bottom line

Our research shows that understanding of 5G's benefits is low in multiple markets, with up to two-thirds of adults stating that they do not know enough about 5G in general as of mid-2020. Among women, the proportion is even higher, at three-quarters. The lack of understanding also peaks among older users.

Figure 13: A substantial proportion of consumers in advanced economies believe that 5G can be harmful to their health

Agreement with the statement: "I do not know enough about 5G" (by country)



Weighted base: Individuals age 16–75 who own a phone or smartphone in Australia (1,915), Austria (952), Belgium (1,909), China (1,953), Denmark (518), Finland (520), Germany (1,868), Italy (1,902), Ireland (948), Netherlands (1,953), Norway (475), Poland (1,909), Sweden (903), UK (3,841)

Source: Global edition, Deloitte Global Mobile Consumer Survey, May–July 2020.

In the vast majority of cases, we would hope that the widespread provision of accessible but comprehensive information about how 5G and other wireless technologies work would put consumers' minds at rest. Mobile operators, mobile handset providers, telecommunications regulators, government communications bodies, and science programs on broadcast and on-demand platforms could, in combination, counter the vast tide of misinformation about 5G. Individual companies and regulators could also work together to constrain the ability to share misinformation, despite the commercial impact that this may have.

What would make an information campaign about 5G successful? Among other things, it would need to be both proactive and reactive. It would need to be designed for all types of user, not just those with a science background. And misinformation would need to be met with information of a similar caliber. Headlines need to be met with headlines. Rebuttals to fake claims need to be expressed using similar channels and similar language. Misinformation spread by well-known individuals should be countered with information from well-known individuals. Celebrities with marketing relationships on the basis of significant social media presence could be asked to become the figureheads of information campaigns. Soap operas with mass market reach could include storylines that feature discussions and explanations about 5G. Without such widespread and accessible efforts, the facts will be ignored. It may not be enough only to post a link to ICNIRP.

Information campaigns also should do more than explain why 5G is safe. They should also educate people about its positive applications—for example, making everyday mobile applications, such as browsing and maps, notably faster. Carriers could also talk about how 5G could make other mainstream applications, such as driving, easier and safer. (A car could provide regular status updates, including video footage, to manufacturers, which would enable them to identify flaws faster.) The telecom industry could also showcase the many applications that 4G has enabled and that consumers have come to depend on.

There should also be debate on effective ways of preventing the proliferation of misinformation on social media. As social media becomes a far more common source of news, checks and balances that control for accuracy while still permitting freedom of speech are becoming increasingly important. Offering the ability to fact-check is one way to help social media users filter facts from fiction, but *all* readers cannot be relied on to have the discipline to verify.

It may not be possible to persuade everyone that 5G is safe. There is likely to be a niche—perhaps less than 1% of the population—that will remain convinced not just that wireless technologies are harmful, but that their deployment is deliberate and that the intent is to cause harm. Unfortunately, while such niche views have in the past lacked widespread amplification, social media has often provided the mechanism for conspiracy theories to flourish and proliferate. If education is to be effective in curbing popular fears, it needs to be compelling, consistent, and pervasive, and it needs to begin now.





The hyperquantified athlete

Technology, measurement, and the business of sports

From cricket to hockey, baseball to basketball, the digital transformation of sports is in full swing. Clubs, teams, leagues, broadcasters, venue operators, and athletes increasingly see the value in analytics and are working to realize that value. Technologies such as computer vision, machine learning, advanced wireless connectivity, and wearable sensors are transforming how athletes

train, compete, and manage their careers. This explosion of data, however, is raising new questions about how best to use it—and how to do so ethically. To begin to address such concerns, we predict that by the end of 2021, multiple professional sports leagues will establish new formal policies around the collection, use, and commercialization of player data.

Data is fundamentally changing sports

If measuring something in sports is conceivable, chances are that someone, somewhere is already measuring it. Hundreds of different metrics can be analyzed today through video analytics and wearables such as harnesses, sleeves, bands, straps, rings, and smart fabrics. Over the past decade, the use of analytics in sports has slowly transformed everything from how talent is identified and assessed to how athletes are trained and managed to how games are played on the field, court, and pitch.²³⁰ The data and analytics revolution has begun to blur the boundaries between many disparate areas of sports, including esports, virtual sports, gaming, broadcasting, fantasy sports, betting, and the live-venue experience. As the use of data and analytics in sports matures, the industry will likely have to address issues about not just the enabling technology, but also increasingly about data rights management, privacy, regulations, monetization, and new ways to experience sports.

Almost all of the world's major professional sports teams have one or more analytics experts on staff with the mandate to find any advantage that can improve the team's chances of winning. In basketball, video capture and analysis have yielded insights that have led to more three-point shots and a greater emphasis on player-load

management. In baseball, intensive statistical analysis of what works and what doesn't has dramatically changed pitcher management, increased the use of the "shift," and replaced small ball with swinging for the fences. Similar analyses now inform how American football teams approach fourth downs and the way soccer teams select shots.

The difference today is that data collection and analysis are becoming increasingly real-time, and it is happening not just on the field and in the gym but around the clock. Further, it is now possible to measure indicators inside as well as outside the body; new layers of positional, biometric, and biomechanical data are creating hundreds of new metrics to feed into decision-making. Finally, advancements in computing power, cloud technology, machine learning algorithms, and high-speed video capabilities are enabling ever more powerful ways to collect and crunch the numbers.

In this era of the hyperquantified athlete, the increasingly urgent question is how to get from data collection (which is easy) to actionable insight (which is hard) to potential monetization (which is really hard)—all the while protecting athletes' rights, ensuring fair play and competitiveness, and meeting the financial needs of leagues, players, and owners.

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Performing in a pandemic

Sports leagues and teams continue to struggle to define their new normal during the COVID-19 pandemic. Leagues of all kinds have modified when, where, and how they play in their efforts to keep their players, coaches, and staff safe and healthy. Some teams are using bubbles (single-site tournaments) to continue play with no live fans, or relying on limited travel and strict behavioral protocols. But many are also leveraging new technologies to provide an extra level of defense.

In the United States, both the National Basketball Association (NBA) and Women's National Basketball Association (WNBA) have offered their players the use of Oura rings to wear during their tournaments in Florida to help monitor their body temperature and respiratory and heart rates as a way to determine health risk.²³¹ A similar technology has been used with promising results by golf's PGA Tour. One player, using a Whoop fitness tracker strap, noticed significant changes in his respiratory rate while he was sleeping, prompting him to get a COVID-19 test despite being symptom-free.²³² He tested positive and removed himself from competition, potentially protecting other players. Whoop straps have now been made widely available to the Tour's players. The German Football Bundesliga as well as the United States' National Football League (NFL) and NBA are using devices to monitor social distancing and enable contact tracing.²³³

These technologies existed prior to the pandemic, but COVID-19 has accelerated their use, giving them the opportunity to prove themselves on the public stage. Athletes are becoming more comfortable with tracking technology as they come to appreciate having more insight into and control over their health and performance. Teams and leagues, meanwhile, have welcomed having additional data to inform health and safety decisions.

Going forward, the COVID-19-driven influx of monitoring technology into sports poses some thought-provoking questions. Will athletes let their organizations increasingly track their health and wellness data in addition to their performance data? Will they accept being continuously monitored while they sleep and relax as well as on the field? After this current pandemic, could monitoring help with outbreaks of other communicable diseases in the locker room? These and similar issues point to the growing need for dialogue and governance over professional sports' practices around collecting and using athlete data.

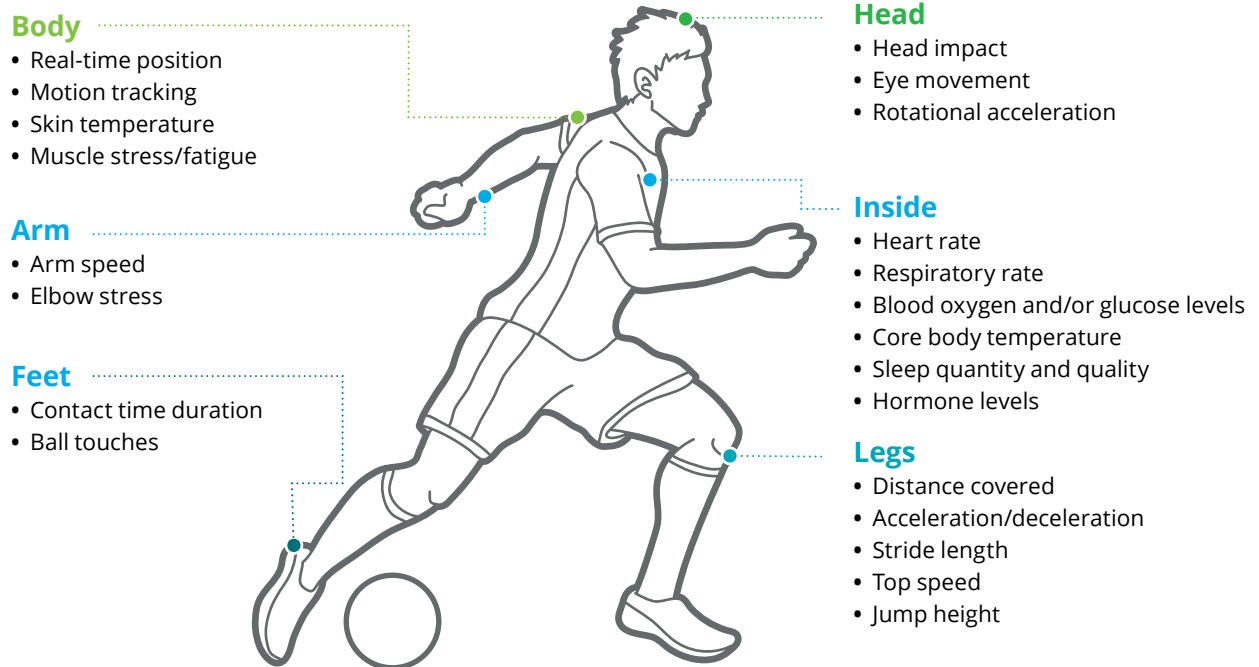
The state of play

For purposes of this article, we will focus on two main types of data that are typically collected from athletes:

Positional/tracking data. Positional/tracking indicators measure, in three dimensions, exactly where a player—or ball, puck, or other object—is located on a field or court. This data can include metrics such as position, acceleration, lateral motion, speed, jump height, and other measures. The data is collected either through video analytics or by sensors in combination with global satellite positioning systems and ground-based wireless networks.

Biometric data. Biometric data refers to any kind of biological information from an individual player. These metrics could include everything from pulse rate and blood glucose or oxygen levels to sweat rate and sleep rhythms. Some biometric measurements, such as heart rate, have been used for decades; now, through digital sensors and ubiquitous low-latency communication networks, many more measurements can be made, in more physical locations, at a greater speed.

Figure 14: Technology has greatly expanded the ways in which athletes can be tracked and measured



Note: This list is not exhaustive.
Source: Deloitte analysis.

The market for quantifying athletes is both diverse and fragmented, with a broad range of options for sensor technology, computing power, data storage, and advanced analytics. Purveyors of these technologies range from “sport tech” companies such as Catapult, KINEXON, Stats Perform, and Zebra to tech giants such as Amazon Web Services, IBM, and SAP, as well as a plethora of startups. The broader sports tech market has also seen a great deal of venture capital interest in recent years, with over 3,000 global deals and funding rounds between 2014 and late 2019.²³⁴

Most, if not all, of the world’s major sports leagues are using these technologies and techniques in various ways. In doing so, they are expanding their view beyond just the technology to

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how they balance the technology's use with players' and coaches' needs. For example:

- Beginning in 2014, the NFL began using radiofrequency identification (RFID) tags in players' shoulder pads, balls, and various areas of the field.²³⁵ Each team is provided their own raw data from that system to analyze and use as they see fit.
- The National Hockey League (NHL) has been experimenting with puck and player tracking for years. After demonstrating the latest iteration of these technologies at its 2020 all-star game, the league is beginning to incorporate them fully.²³⁶
- Players in the Australian Football League have been using positional sensors and heart rate monitors during games for the last few years.²³⁷ They even use the data to make in-game adjustments.
- In 2017, Major League Baseball (MLB) approved the use of Whoop straps by players on a voluntary basis to track information that they can use later to better understand their performance.²³⁸ This is in addition to other approved wearables that allow players to measure factors such as arm stress.²³⁹

Powering performance at the United States Olympic & Paralympic Committee

Scott Riewald is the senior director for high-performance projects at the United States Olympic & Paralympic Committee (USOPC). His job is to build capabilities for and to improve the collaboration between the technology, innovation, and data and analytics teams throughout the USOPC. He has been strengthening connections between these different groups and, in his words, is now "pulling those threads to bring everybody closer together to create a unified approach of how we use data to support Olympic and Paralympic athletes."²⁴⁰

Five years ago, the USOPC realized that it was not where they wanted and needed to be with regard to data and analytics, and made the strategic decision to focus on the opportunity to expand these capabilities. The USOPC works with thousands of elite athletes in scores of different sports, giving the organization access to expansive data sets that create opportunities to discover "hidden insights."²⁴¹ Riewald and the USOPC also work with the various Olympic and Paralympic sports' National Governing Bodies to establish best practices, provide more consistency around data and analytics, and recommend which technologies to use.

The USOPC utilizes its Athlete 360 performance management platform to collect and analyze athlete data. This system was designed to be device-agnostic so that data from different sports from different sources and different pieces of technology (such as wearable sensors) can be easily aggregated. In the next two to three years, Riewald and the USOPC aim to be able to capture more data in a less invasive manner. As an example, Riewald points to the skin-mounted electronics pioneered by the Rogers Research Group at Northwestern's McCormick School of Engineering.²⁴² These devices, when placed on athletes, can noninvasively measure performance-impacting indicators such as sweat rate, electrolyte loss, and blood glucose levels.

As its capabilities mature, the USOPC is looking beyond simple data collection and integration in the quest to uncover meaningful and impactful insights for all athletes. Riewald wants to use data to better understand causality—what performance measures preceded a particular result—to better define the "pathways to success."²⁴³ His team works hard to make athletes and coaches understand that data collection and analysis are important. They want to make the value proposition clear, convey information so it drives curiosity, and, ultimately, help drive positive behavioral changes. Riewald emphasizes: "Thinking about ways in which you can convey information in order to achieve behavioral change is what underpins what you're trying to get from data-gathering."

Riewald is acutely sensitive to these developments' implications for privacy, security, and ethics. Every day, more and more technology becomes available to monitor more and more aspects of an athlete's life. Trainers and coaches can potentially track everything about an athlete every minute of the day. To balance the benefits against the risks, Riewald says, organizations need a clear reason to monitor athletes and must prove its value to the person being monitored. He warns: "Just because you can measure something doesn't mean that you should. I really believe that we walk a fine line here. We want to provide relevant data that positively impacts athlete health and performance, without doing so much that we risk athletes and coaching going into data overload."²⁴⁴

A competitive edge through hyperquantification

The famous cycling coach Sir Dave Brailsford once said, "It struck me that we should think small, not big, and adopt a philosophy of continuous improvement through the aggregation of marginal gains."²⁴⁵ Hyperquantification is helping teams, leagues, and players discover these gains across the life cycle of their sport—talent identification, training, pregame preparation, game play, postgame analysis, and rest and recovery. Of these, three areas that could see further innovation in the near future are:

Talent identification. If a team is going to make a significant financial investment in a player, it wants to be confident that the player has the skills, raw physical ability, medical profile, and mental makeup to succeed. This process is becoming more virtual, especially in the wake of COVID-19. In addition to traditional in-person assessments, teams are increasingly using automated video analysis and positional and tracking data in their scouting. These advances have helped to expand the pool of potential professional players to include those that scouts may not be able to travel to see. For example, one pro football hopeful could not attend traditional scouting events due to personal injury and the COVID-19 pandemic, so he submitted his player-tracking data from college games to prove his speed in a real-world environment.²⁴⁶ In the near future, more biometric data will likely be added to

the mix to augment medical data for predicting long-term performance. One day, teams could have access to a player's biometric data from his or her participation in youth sports through high school and college programs. While data is unlikely to completely replace traditional evaluative methods, it is poised to provide another set of objective measures that will likely become more and more important.

In-game decision-making. Today, most biometric data collection and analysis happens during training and practice, or to help with postgame evaluations. Its use is still not widespread in actual games, and even if in-game data is collected, it typically is not used for any immediate coaching decisions. In fact, some leagues prohibit the in-game collection and use of biometrics unless explicitly approved by the league. On the other hand, in-game positional and tracking data is already widely used. Leagues such as the NFL, NHL, and the Mexican football league Liga MX have all done this to some extent, and they have gained better insight into how game strategies are working.²⁴⁷ As teams gain more experience and data collection becomes easier and analysis faster, real-time analytics that guide how coaches and managers direct their teams may come into wider play, identifying who might be at risk of injury, who is getting close to exhaustion, who might be out of position, and who may be primed to make a big play.

Injury reduction. The holy grail for many athletes and teams is being able to predict when conditions may heighten the risk of injury. For teams, it means more wins and more revenue; for athletes, it means having information that can help them extend their careers—and earnings potential—as much as possible. Predicting injuries more effectively requires measures that help balance exertion and strain with the proper amount of recovery time and sleep. The potential benefits are vast: One study estimated that the NFL lost more than US\$500 million in 2019 due to injuries.²⁴⁸ It's no wonder that the NFL recently partnered with Amazon Web Services to use machine learning and computer vision technologies, powered by multiple different data sets, to gain insight into head and other injuries.²⁴⁹

From measuring to monetizing

The hyperquantification of athletes can provide more efficient training, improve competitiveness, and increase the likelihood that star athletes stay healthy—benefits that, as organizations well know, can potentially lead to higher attendance, more sponsorships, and greater broadcast viewership.

What may be significantly harder is to figure out how this digital revolution can create new revenue streams for teams, leagues, and players themselves. Although innovations are taking place in smaller sports, many major leagues are just starting to test how they can monetize players' biometric and positional data, with some leagues even banning the commercialization of player data. There is still much to be done to establish clear data-ownership policies, provide equitable revenue distribution, and ensure player protections. But the potential for monetizing player performance data is so great that it will likely encourage the involved parties to begin addressing these concerns in the short to medium term.

We see several areas for experimentation and innovation over the next few years:

Fan engagement. Leagues and players' associations can work with broadcasters and venue operators to use player data to improve the fan experience and create new ways for fans to engage with sports and athletes. This could lead to new direct-revenue streams, generate new marketing and sponsorship opportunities, and/or have a halo effect on already established revenue streams. For example, the Professional Squash Association (PSA), working with Sports Data Labs, tracks and displays players' heart rates in real time during broadcasts.²⁵⁰ The goal is to give fans a better understanding of the game's athleticism as well as create more excitement around the gameplay; any revenue generated through the biometric data is shared among the league, players, and partners.²⁵¹ Similarly, the handball league LIQUI MOLY Handball-Bundesliga has teamed up with KINEXON and Content Stadium to stream real-time player performance information in stadiums and across social media platforms.²⁵²

Licensing. Another way for players and leagues to make money is by licensing player data to organizations such as fantasy sports leagues, sportsbook companies, broadcasters, and health and fitness companies. In 2017, the NFL Players Association came to an agreement with Whoop that, among other things, allowed players to sell their personal health data collected by the wearable.²⁵³ Many leagues already have strategic partnerships with sportsbooks, such as the PGA Tour with DraftKings and the NBA with William Hill, laying the groundwork for emerging opportunities.²⁵⁴ Other types of opportunities also exist: During its short life, the Alliance of American Football, in partnership with MGM, was developing an application that would enable betting during games where odds would be adjusted based on data from player wearables.²⁵⁵

One league that sees such opportunities clearly is the WNBA. In its recently enacted collective bargaining agreement with players, they recognized the potential for data collection and use, saying that “the use of wearables and other in-game technology provides a unique opportunity for the WNBA with respect to enhanced broadcasts, differentiated fan experiences, player health, and revenue generation.”²⁵⁶

Key matchups

Any opportunity to improve athlete performance or to increase the amount of money in sports is clearly extremely appealing. However, no emerging technology or change in approach is without consequences, some expected, some not. We see three critical areas that should be addressed if hyperquantification is to come into its own:

Quantity vs. quality. Coaches and their staffs have traditionally relied on gut feel and experience. Even today, some use analytics more widely than others, striking their own balance between data and instinct. With new positional and biometric data added to the mix, the analytics becomes more complex and the insights harder to communicate. To heighten the data’s utility, much work should be done to determine what measures are most critical—what data will truly make a difference, and what will merely create noise in the system. There is also debate over whether to believe the data over seeing results with one’s own eyes. Are there ways to properly quantify the magic of once-in-a-generation players? Finally, some worry that overanalysis will lead to a less entertaining product for fans, essentially “ruining” sports. For example, in MLB, longer games and less action (more strikeouts and home runs) can be attributed to the extensive use of analytics.²⁵⁷

Performance vs. privacy. Questions abound about who ultimately owns player data, including any sensitive health information that teams could collect. A number of professional sports leagues in the United States have established guidance and rules around this issue in their collective bargaining agreements with players’ associations. These rules specify how player data can be collected, whether or not its collection and use is voluntary, how it will be protected, and how it can be used. Some leagues have also established sensor and wearable committees that approve device and data use. For example, the NFL states that “each individual player owns his personal data collected by sensors,”²⁵⁸ while the NBA’s collective bargaining agreement says that “a player will have full access to all data collected on him from approved wearables.”²⁵⁹ But although these agreements do afford some protections and benefits, the speed of technology development and the rapid evolution of potential commercial opportunities are not necessarily compatible with the long-term nature of collective bargaining agreements, which last years.

A focal point in this debate is what is best for players. Many athletes are uneasy about using wearables to collect their data, especially biometric data. Some feel like they are part of a laboratory experiment, while others worry that, even though such use is prohibited, biometric data collection could bias contract negotiations. Some also voice concerns that required data collection will increasingly encroach on activities outside of work, such as sleeping. An example of this conflict is “Project Red Card”: A group of hundreds of former and current soccer players in the United Kingdom are suing sportsbooks and data-processing companies, claiming that they have illegally profited from player statistics.²⁶⁰ The details of this lawsuit are still emerging, but the results could eventually shape how many types of player data can be commercialized, as well as who ultimately profits.

Betting vs. banning. By some estimates, the global sports betting market is predicted to top US\$150 billion by 2024.²⁶¹ With the 2018 repeal of the Professional and Amateur Sports Protection Act in the United States, and the legalization of sports gambling by many US states, American leagues in particular are hungry to tap into new revenue sources.²⁶² One of the emerging issues in this space is the potential for using individual athlete data for bets, either through using biometric and positional data to set odds, or by betting on specific measures such as pulse, top speed, and

acceleration.²⁶³ Such uses could generate substantial pushback from players, who may see it as a gross invasion of privacy—but it could be a different story if they could significantly profit from it. The state of Illinois has gotten ahead of the curve by banning the use of biometrics in sports betting unless the relevant players' association gives permission.²⁶⁴ Even though the desire for this type of wagering exists, the devil is in the details, and players, leagues, unions, legislators, and commercial businesses should all come to the table to decide what is best.

The bottom line

In the near future, it may become commonplace for fans sitting in a stadium or arena to look up at the scoreboard and see players' top speeds in real time, or a ranked list of players' level of physical exertion during the game. The same information could also be broadcast to viewers at home and streamed on social media. Fans, both at home and in person, could use their mobile devices to place a bet in real or virtual currency on the outcome of the next play, with the odds influenced by positional and biometric data. Ideally, this would all be backstopped by robust agreements among all involved that guarantee voluntary collection of data, protect players' rights, provide for proper data security and privacy, and set out detailed licensing and compensation rules.

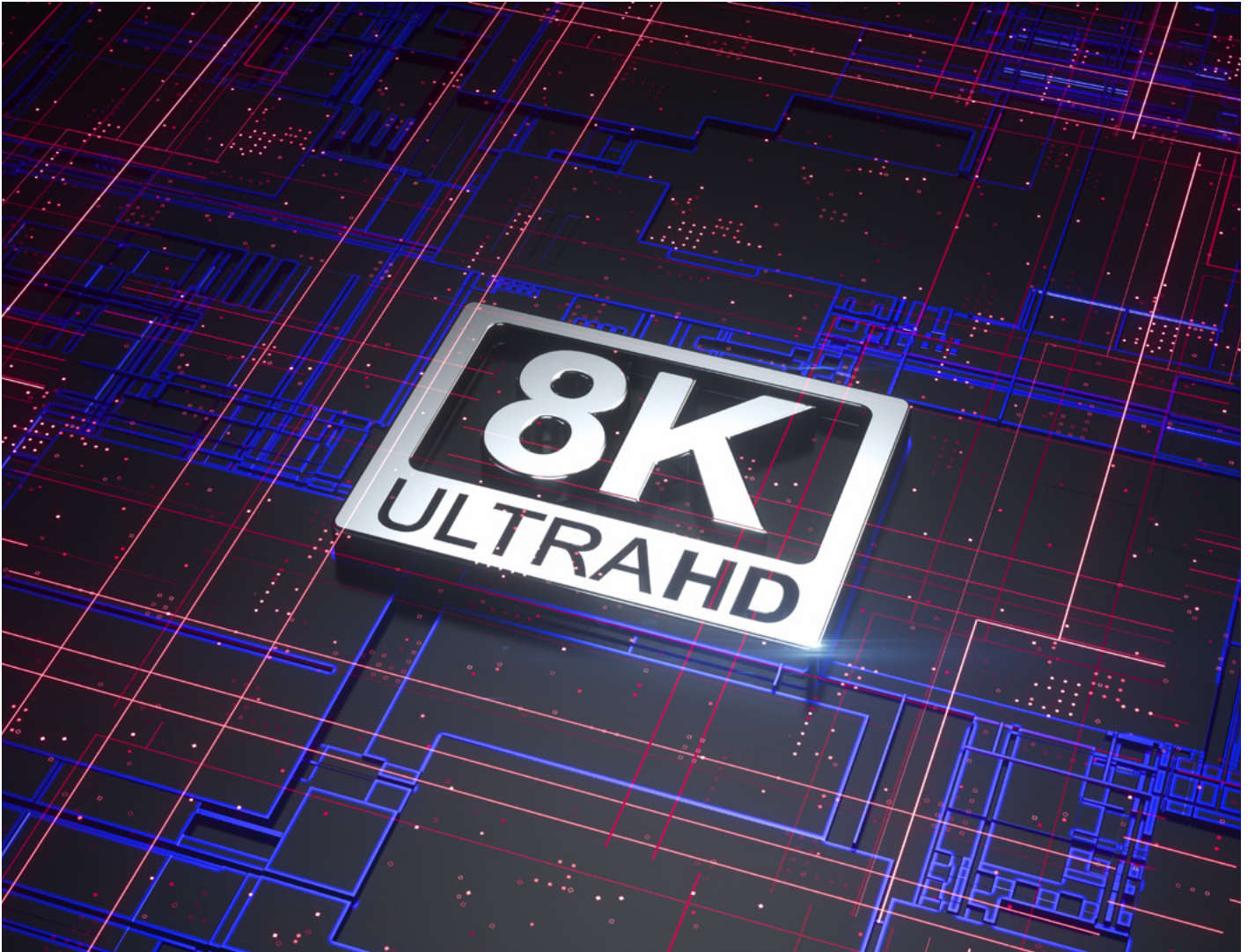
These issues should be approached with great care, as the emerging hyperquantification landscape has the potential to become much more complex in the near future. As Yogi Berra once famously said, "If you don't know where you are going, you might wind up someplace else." Critical open questions include:

- How will advances in computer vision such as automated video analysis, sensor technologies, and machine learning accelerate the state of the art?
- Would players benefit enough financially from sharing their personal and performance data to entice them to do so?
- Will a standard agreement emerge between players and leagues across sports around the collection, use, and monetization of private and sensitive information?
- How will performance data ultimately be used to enhance the in-stadium and remote fan experience?

For the hyperquantification of sports to succeed, the athlete should be at the center of every decision and conversation. Athletes, trainers, coaches, player agents and representatives, and business leaders should become knowledgeable about the enabling technologies and their responsible use. Those collecting and using the data should convincingly demonstrate and effectively communicate its value. Athletes should see that it is in their best interest to share their data and allow for its thoughtful application. Above all, it is critical that trust be built and maintained among all parties. Without it, the potential gains may never be fully realized.



Therapy, Timing,
Torso, Tran, Tra
Transformation, Treat
Trends, Percer
Performance, Perspir
Pessimism, Physiothe
Pirates, Play
Positioning, Posse
Potent, Power, Power
Practice, Prevel
Professional, Prof
Promising, Pr
Prote



TV's New Year's resolution

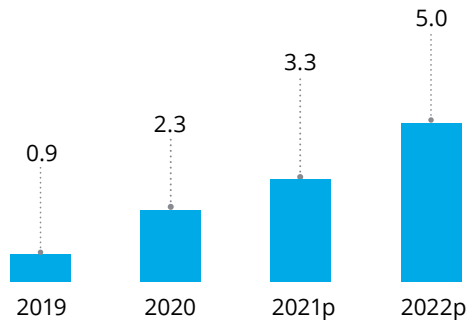
The start of the 8K wave

If you have a 4K-resolution TV screen—and many consumers do these days—you're used to seeing your favorite shows, movies, and videos with few visible individual pixels. But over the next few years, those images may be about to get even sharper. We predict that 8K—an upgrade and complement to 4K resolution—will generate US\$3.3 billion in global revenue in 2021, with this amount rising steadily over subsequent years (figure 15).²⁶⁵ These revenues will come

predominantly from sales of 8K TV sets to consumers (an anticipated 1 million units with an average selling price [ASP] of US\$3,300), with the standard becoming increasingly popular for the largest television set sizes. In addition, sales of equipment (such as cameras, monitors, storage, and computers) related to the creation and production of 8K content should generate hundreds of millions of dollars globally for the year.

Figure 15: 8K sales will likely surge over the next two years

Global revenues from 8K panels, US\$ billion



Source: Deloitte forecast based on data from IHS Markit, Display Supply Chain, 2020.
Deloitte Insights | deloitte.com/insights

What is 8K?

The 8K standard is named after its resolution, which is 7,680 horizontal x 4,320 vertical lines on a 16:9 aspect ratio screen, equivalent to about 33 million individual pixels.²⁶⁶ This compares to 8.3 million pixels for 4K.²⁶⁷ The 8K standard also includes specifications for:

- Frame refresh rate, which varies from 24 to 120 frames per second
- Color range, which spans every color available in nature as well as additional artificial colors, as well as improved dynamic range related to brightness²⁶⁸
- Audio, which is upgraded to 22.2 channels of surround sound²⁶⁹

Why some people are skeptical about 8K's mass-market adoption

At first glance, consumer adoption of 8K seems to face three principal hurdles:

- **Content.** Content is what makes devices useful; without it, a device may be mostly redundant. However, we expect that less than 0.1% of all video content created in 2021 will be in 8K,²⁷⁰ and that 8K will be an even smaller proportion of the total base of video content (TV programs, movies, user-generated content, and video games).
- **Cost.** 8K TV sets are likely to cost up to tens of thousands of dollars for premium models. The starting price of 8K TVs, at around US\$1,500, is likely to be far higher than for 4K TVs, which are available for under US\$300.
- **Comparison.** In blind tests, consumers have struggled to distinguish 8K video from 4K.²⁷¹

These hurdles may suggest that 8K is unlikely to flourish in 2021. However, our view is that these challenges can be surmounted. There is already abundant content that can be viewed in 8K

resolution, and that quantity will likely grow over the coming years. The cost of entry-level 8K TVs should decline to about US\$1,500 by the end of 2021. And the most common comparison of an 8K TV to a 4K one is likely to be based on physical size and peak pixel count, rather than the screen definition used in day-to-day viewing.

Surmounting the content hurdle

With 8K representing less than 0.1% of all video content created in 2021, one might think that viewers would have trouble finding 8K content. But according to our estimates, enough 8K content already exists for an owner of an 8K TV to spend every hour of every day throughout 2021 watching 8K material—without watching a single repeat.

Further, the lack of native 8K content is, in itself, not a major constraint to the purchase of 8K TV sets. Back in 2012, the lack of native 4K content when the standard was launched was expected to deter purchases of 4K TVs. But the relative paucity of 4K content did not faze many consumers. The majority of TV sets sold since Q4 2018 have been 4K despite

only a minority of broadcast, satellite, video-on-demand, and disk content being available in native or remastered 4K. If history repeats itself, we would expect that a large proportion of consumers would buy an 8K panel if it were close in price to a 4K set of the same size. And these consumers would be content with their purchase even if they watched 8K content only occasionally.

If history repeats itself, we would expect that a large proportion of consumers would buy an 8K panel if it were close in price to a 4K set of the same size.

It is also important to note that consumers who buy an 8K TV set in 2021 may be buying it for the long term, expecting to keep it for five to seven years (the expected life of a TV set before it is replaced) or more. This allows ample time for more 8K content to become available.

But where will 8K content come from in the near future? We expect that in 2021, at least six sources of content will generate images that can be shown in 8K or that require an 8K screen.

Source 1 of 6: Upscaling

The main workaround for the lack of native 8K content (that is, content filmed in 8K) is upscaling, which takes place at the television set. This is the process whereby an input at a lower resolution, such as 4K, is converted into an 8K image using local (on-device) artificial intelligence (AI) algorithms and edge computing. Upscaling is considered successful if the viewer perceives an image converted to 8K as one that was originally captured in that resolution.

Upscaling is considered successful if the viewer perceives an image converted to 8K as one that was originally captured in that resolution.

Ample 4K content already exists that could be “fed” into an 8K TV with upscaling capability. Netflix, as an example, now has one of the largest 4K catalogs in the world, with over 1,000 titles offering a total of tens of thousands of hours of content.²⁷²

In upscaling, a TV set analyzes each frame and applies AI to identify the many different objects that may be in it, be it a pair of sunglasses, a burger, or a building. An upscaling engine then converts each 4K-resolution object into an 8K one, restoring edges, repairing any compression artifacts, and coloring each pixel as accurately as possible.²⁷³ To inform this conversion, the TV set draws on a database that may contain tens of thousands of image references.²⁷⁴ Upscaling quality for 8K TV sets should improve over time, as more conversions are done and the collective body of knowledge per vendor on how to optimize scaling grows. 8K TV upscaling algorithms can be updated over the air.²⁷⁵

Upscaling is not new to 8K. It was a feature of the first 4K sets in 2012 to address the lack of 4K content then available.²⁷⁶ Back then, upscaling was less sophisticated and convincing. Initial approaches were based on duplicating neighboring pixels: If an empty new pixel was next to a blue one, a blue pixel would fill the space, often resulting in a block of four blue pixels. Later versions of upscaling averaged up to 16 neighboring pixels in each direction to fill an empty new pixel, but again, this can create unsightly artifacts. However, with the development of more sophisticated, AI-driven techniques, these problems are well on their way to being resolved.

Upscaling from HD to 8K is also possible. This requires adding 15 pixels per HD pixel, a far more challenging conversion than for 4K to 8K. But as techniques improve, artificially generated 8K video may become ever more realistic, even from HD.

Upscaling can also be deployed as part of a compression process. Native 8K content is downsampled to 4K, and then restored via upscaling to 8K at the TV set guided by instructions added to the compressed video file. This approach, commercially known as smart downscaling, promises significant reductions in required bit rate for transmission. 8K high-efficiency video coding (HEVC) content can be compressed from 40 megabits per second (Mbit/s) to 25 Mbit/s,²⁷⁷ and AV1 (AO media video 1)-encoded 8K can be reduced from 35 Mbit/s to 17 Mbit/s.²⁷⁸ This approach enables 8K content to be delivered over broadband, satellite, or terrestrial broadcast connections originally designed for 4K.

Source 2 of 6: Remastering very high-definition analog and digital content
8K resolution is not completely new. Movies shot on 70mm film have a resolution equivalent to 8K.

A few movies have already been remastered in 8K (ultra-high-definition 4K digital remasters of 65mm and 70mm movies have already been created). One of the first to undergo this process was 2001: A Space Odyssey. This remastered version was broadcast by NHK in December 2018 on its BS8K channel.²⁷⁹ In March 2019, NHC also broadcast an 8K version of My Fair Lady.²⁸⁰ Dozens of other major movies that were shot on 65mm or 70mm could undergo the same treatment. Most iMax movies are shot on 65mm or 75mm as well,²⁸¹ so films created for iMax cinemas, or with an iMax version available, could be converted to 8K.

Content shot in 6K, principally to provide more versatility in producing a reframed 4K master, may also be upscaled to 8K. The third season of Netflix's House of Cards, for example, was shot in 6K. The season was released as 4K, but the 6K masters have been archived.²⁸² Netflix's Mindhunter was also shot in 6K for reasons similar to House of Cards.²⁸³

Source 3 of 6. Content shot natively in 8K

A few major movies and TV series have already been shot in 8K, although they were released at 4K and lower resolutions. These include:

- *Homecoming's* second season on Amazon Prime
- *Money Heist's* fourth season on Netflix
- *Mank*, a black-and-white biopic of Citizen Kane's cowriter, directed by David Fincher
- *The Eddy*, a musical drama by director Damien Chazelle, on Netflix
- *Guardians of the Galaxy 2*

In the future, once a large enough base of 8K TV sets exists, native 8K content could be released as an 8K stream or broadcast.

Source 4 of 6: User-generated content

User-generated content has exploded in the last decade. The caliber of photographic and video tools available to consumers at relatively modest prices has steadily grown, thanks to the proliferation of the smartphone. One of the most popular applications for smartphones is photography, and in the near term, this may be one of the major sources of content that requires an 8K display.

Most current smartphones have at least one 12-megapixel (MP) camera, which capture images in 12 million pixels (dots of light which, in aggregate, make up each frame). At least a billion smartphones with 12MP capability are likely to be in use in 2021. 12MP images can only be displayed in their full resolution on an 8K TV: A 4K TV, with a mere 8 million pixels, is insufficient, but 8K televisions' 33 million pixels are ample for 12MP. Mobile devices have collectively captured over a trillion images, of varying artistic caliber but consistent pixel count, which may only ever be seen in their full resolution when displayed on an 8K TV. Smartphones with 64MP and 108MP cameras are also in the market, and their full resolution exceeds that of even an 8K TV.²⁸⁴

One of the most popular applications for smartphones is photography, and in the near term, this may be one of the major sources of content that requires an 8K display.

The quality of photos taken on a smartphone, particularly when natural light is available, is very high. These photos may look spectacular when shown off on an 8K television screen, especially if the TV incorporates software that sharpens the image and removes noise.

The next frontier of widespread 8K video is also fast approaching. A few high-end smartphone models offered 8K video capture as of August 2020, namely the Samsung S20, Xiaomi 10, and Red Magic S3. This number is likely to increase over 2021 and beyond. These devices can capture content in 8K at up to 24 frames per second;²⁸⁵ over the next couple of years, the frame rate is likely to increase. Most owners today may only dabble with 8K video, partly because of its large storage requirements (600MB per minute) and because of the slower frame rate relative to 4K and HD capture. However, consumers who do shoot videos in 8K capture could share this content via online platforms such as YouTube or Vimeo. Over the course of 2021 and the coming years, the volume of 8K videos captured on a smartphone should steadily grow as smartphone memory capacity increases and frame rates go up.

Source 5 of 6: Prosumer content captured in 8K or greater than 4K

Prosumer photographers, whose subjects span birthdays to corporate videos, may start to experiment with 8K capture, as could aspiring moviemakers with smaller equipment budgets. These content creators now have access to compact 8K cameras whose cost starts at about US\$4,000, available from brands including Canon and Sharp.²⁸⁶ A decade ago, 8K prototype cameras weighed hundreds of kilograms; Canon's current 8K camera weighs less than one kilogram.

Cameras that can capture content in 6K, which can then be upscaled to 8K are also available. As of August 2020, companies offering cameras with 6K capture included Canon, Sony, Panasonic, and Blackmagic Design.

8K prosumer content is already available online to watch on 8K TVs.²⁸⁷ YouTube has accepted 8K uploads since 2015, and Vimeo has thousands of videos tagged as 8K.²⁸⁸

more to amateur users than to the much smaller population of professional game players, who favor higher refresh rates over resolution and would likely keep on gaming in 4K or HD.²⁹²

Source 6 of 6: Game consoles with 8K support

4K has already been a differentiator for prior generations of game consoles, and 8K may prove the same. The year 2021 will be the first full year in which a new generation of 8K-ready game consoles will be sold. There will probably be few titles to play in this resolution in 2021, but over the next five years, more and more 8K games should become available.²⁸⁹ The latest consoles have been designed to cope with much larger file sizes,²⁹⁰ with eight core processors that are able to deal with more complex video.²⁹¹ That said, 8K screens will likely appeal

Prosumer photographers, whose subjects span birthdays to corporate videos, may start to experiment with 8K capture, as could aspiring moviemakers with smaller equipment budgets.

8K's uses beyond entertainment

8K can have applications far beyond its use in entertainment. For example, one potential use of 8K could be for remote working. An 8K panel could be used to display multiple pages of content that a person or team is working on more crisply than would be possible at lower resolutions. These pages—perhaps a blend of diagrams, video calls, charts, and data sheets—could all be visible to a remote team scattered in different locations. This would be an upgrade from working from a single screen or having an array of monitors.

Office locations already use large panels for video calls and collaborative working. But for people expecting to work predominantly at home during 2021, large panels equipped with 8K could improve productivity due to their superior resolution. Documents viewed close up (from 20–30 centimeters), which may be pixelated on an HD or even 4K screen, would look clear on an 80-inch screen with 8K screen resolution. Video calls with dozens of colleagues could also be more practical on a large screen, with every individual discernible versus being visible only as a blurred rectangle.

The cost of 8K panels for work purposes may be tax deductible and/or subsidized by an employer. And they could of course switch applications once the working day is done, and be used to watch entertainment programs or play video games instead.

8K screens could also be used to display for online exercise classes, a content genre whose popularity surged during lockdowns while people were not able to go to the gym, go for a run, or ride a bike. The falling price of HD monitors and cameras enabled the first phase of online, interactive exercise classes featuring treadmills and static bikes with integrated screens. Large 8K screens, displayed on a wall, would enable instructors and fellow athletes to be shown larger—even life-size. Screens could also be used to show performance metrics from fitness bands and smart watches.²⁹³

Still another use for 8K panels is for “digital wallpaper” that decorates part of or all of a large screen. Ever since the advent of digital screens, digital images have been used as screensavers, showing everything from tropical fish to fractal images to personal photos. Vendors of TV streaming peripherals have also included screensavers in their products.²⁹⁴ 8K TVs, which display a greater range of colors than 4K sets, can expand the range of images that can be effectively shown, including artwork from museums and private collections. A few digital art-as-a-service providers are already in business, and their number is likely to grow as more 8K sets become available.²⁹⁵

Surmounting the cost hurdle

One major barrier to consumer adoption of 8K screens is their cost—for now. But in the near future, the cost is likely to drop substantially, especially when one calculates the cost per hour of viewing. Combined with TV screens’ appeal as a status symbol, this may be enough to push many consumers to consider an 8K set good value for their money.

8K panels should steadily fall in price

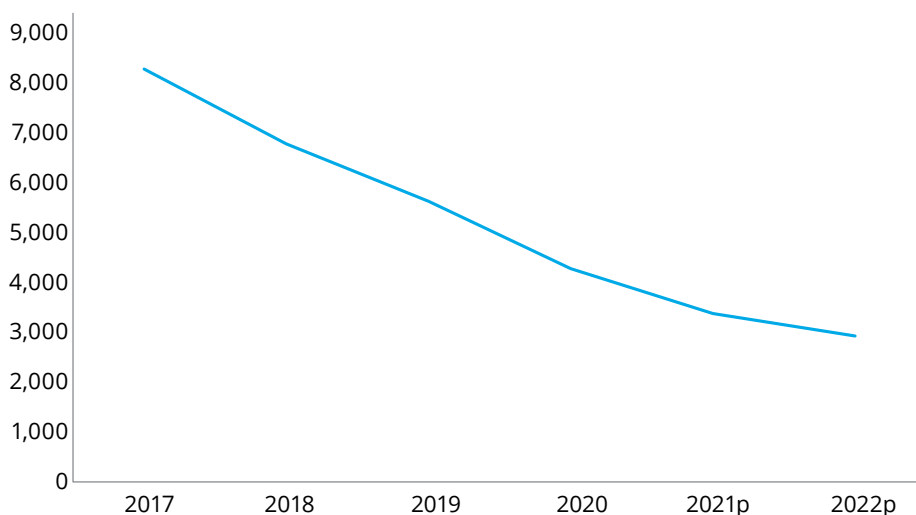
8K sets are unlikely to enjoy the exact same pace of adoption as 4K sets, which took only seven years from their launch to become the most popular resolution in 2019, when over 100 million 4K TV sets

were sold.²⁹⁶ 8K adoption will be slower because of their higher costs and larger size. But the dynamic for 8K is likely to be the same: As price falls, demand will ramp up commensurately.

In 2017, the ASP for 8K sets was more than US\$8,000.²⁹⁷ The following year, it had decreased to about US\$5,500.²⁹⁸ By the end of 2021, we expect that entry-level 8K TV sets will be offered for US\$1,500 or less, with an ASP of US\$3,300 (figure 16). And as prices have fallen, sales have grown. In 2017, about 2,400 8K TVs were sold.²⁹⁹ In 2018, the first full year in which 8K TV sets were available,³⁰⁰ sales reached 18,600 units. In 2021, we forecast

Figure 16: 8K panels should fall in price in the short to moderate term

Average selling price of 8K panels, 2017–2022, worldwide



Source: IHS Markit for 2017–2019; Deloitte forecast for 2020–2022.

1 million unit sales globally, compared to 550,000 the prior year. Though this is still a drop in the ocean relative to the approximately 220 million sets of all resolutions sold in 2018, the upward trend is clear.³⁰¹

8K sales are likely to accelerate as the cost differential between 8K and 4K panels narrows. The smaller the differential, the more likely consumers will opt to future-proof, particularly for larger, higher-priced TV set sizes (65-inch or greater).

Moreover, as demand for 8K TV sets rises, supply is likely to ramp up, further driving down their price. In 2018, the global manufacturing capacity for 65-inch displays (of all resolutions) was just 12 million.³⁰² In 2022, we expect this capacity to increase to support the production of 154 million 55-inch TVs and 37 million 65-inch TVs, with much of the incremental capacity focused on 8K screens. This also parallels what happened with 4K: The number of brands offering 4K TV sets globally more than doubled between 2016 and 2019, from 30 to 70.³⁰³

While lower prices are good news for consumers, the rate of price decline may, in the medium term (from 2025 and on), largely cancel out any increase in revenues for 8K set manufacturers and retailers. Purveyors of 4K sets have already experienced this phenomenon. In 2020, 4K TV unit sales in the United States were expected to grow by 12% to 25 million, but revenues were projected to increase by a mere 2%.³⁰⁴

Televisions, including 8K models, can cost as little as 25 cents per viewing hour

Spending US\$2,500, or even US\$1,500, for an entry-level 8K TV may appear very hard to justify. But with an expected lifetime of seven years and an average usage of three to five hours per day, a US\$2,500 set would cost less than a dollar a day and about 25 cents per hour of viewing time, with the cost shared among the entire household.

To put this into context, many consumers are likely to spend more per year on a smartphone. Multiple brands of smartphones cost more than US\$1,000, and their ASP across all markets is about US\$380.³⁰⁵ The expected lifetime for phones purchased in 2020 is forecast at only 2.7 years.³⁰⁶ Hence, a household with three people may spend around US\$3,000 on smartphones over a seven-year period if each person purchases a US\$380 smartphone, and around US\$7,800 if each person spends an average of US\$1,000 per device.

Few consumers are likely to calculate the cost per hour of a new TV set. But the volume of usage of a new 8K TV and the range of applications for which it can be used—as well as the satisfaction of showing a new, large, device to friends and family—are all factors that can help justify its purchase.

More time at home means more TV sales

TV sets were popular sellers during the lockdown phase of the COVID-19 pandemic in 2020. In the United States, unit sales of TV sets 65 inches or larger went up by 52% in the first half of 2020, and larger sets over 65 inches were up 77% in the second quarter.³⁰⁷ In Germany, TV sets sold strongly even as lockdowns were relaxed, with year-on-year sales up 37% in May 2020 and 21% in June 2020.³⁰⁸

Should a degree of lockdown continue through 2021, at least until a vaccine is widely available and applied, citizens may continue to spend more time at home and less time in indoor venues such as cinemas. To help pass the time, they may continue to choose to upgrade their home entertainment, partly by using savings made from not going out.

New business models may make televisions more affordable

The revenue streams for TV vendors have historically remained largely the same. The manufacturer generates the bulk of revenues at the point of sale, and then waits until the sale of a replacement set to generate further revenues. This model has worked for makers and sellers of television sets, as well as multiple other appliances, for decades.

However, connectivity enables this business model to change in ways that can make TVs more affordable by monetizing information about usage habits. Rather than collect all revenues in one go, a vendor could trade gross margin at the point of sale for revenues from advertisers and content owners throughout the TV set's life. This could enable TVs to be sold at a lower price, making the TV set more cost-competitive while generating potentially higher revenue over the device's lifetime ownership. For consumers, this may mean that they are able to acquire an 8K set for the same budget as a 4K set. The only requirement would be to connect the TV and agree to terms and conditions.

Rather than collect all revenues in one go, a vendor could trade gross margin at the point of sale for revenues from advertisers and content owners throughout the TV set's life.

A connected TV generates information useful to an array of vendors every time it is used. For content vendors, the TV can collect and share information about programs watched, channels chosen, and apps watched and deleted. It could also collect data on what programs are clicked on or, once started, paused or abandoned, which can provide a feedback loop to content creators or content aggregators such as video-on-demand companies. Additionally, a connected TV can serve as a shop front for content providers' apps. Space on the TV set can be rented to vendors, or commissions collected with every download. And it could be used to show ads distributed by the TV vendor, which could disintermediate TV broadcasters and other entities that have traditionally sold advertising space.

A connected TV can also collect data on devices in the home to help build a profile of the household based on the quantity and quality of devices owned. It could, for example, be connected to a smart doorbell or to a video baby monitor to be able to show who is at the door or to reassure parents that a baby is sleeping. The ability to collect additional data will depend on each market's specific data privacy regulations.

This kind of business model is not new, of course.³⁰⁹ Though relatively novel to TV, other devices already collect or enable the collection of data useful to advertisers. Considering its success, TV is likely to adopt this model over the course of the 2020s.

The rising size of TV sets is likely to make a stronger case for 8K

TV screen size has become steadily and considerably larger ever since TVs were first invented. Between 2004 and 2019, the average screen size of TV sets in the United States increased from 25.4 inches (as measured on the diagonal from the screen's bottom left to top right corner) to 47 inches. This translates into a steady rise in the average screen size of the installed TV base of one inch per year.³¹⁰

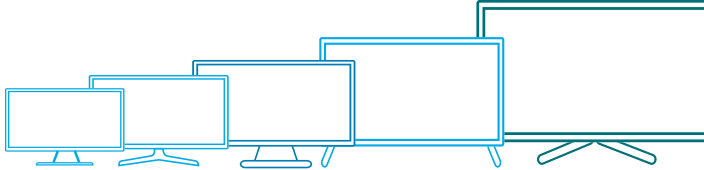
The growth in TV screen size has been enabled by the shift to flat panels, which cost far less per square inch of screen to manufacture than those based on older technologies. Between 2014 and 2019, the average cost per square inch of screen in the United States fell from US\$2.15 to US\$0.39, an 82% decline.³¹¹ Concurrently, sales of large-screen sales increased. According to one analysis, the most common size of TV set sold in 2019 in the United States was 65 inches. In the same year, the price of 65-inch sets fell by 25%.³¹² In the first half of 2020, US unit sales of TV sets 65 inches or larger were up by 52% in the first half of 2020, and larger sets over 65 inches were up 77% in the second quarter.³¹³

The larger the TV screen, the more likely a customer may be to opt for 8K so as to have a perfectly smooth, pixel-free

image. The number of pixels on the screen at a given resolution is constant regardless of screen size; as screen area increases, the number of pixels per inch (PPI) for each resolution declines (figure 17), resulting in a grainier image. On a 36-inch HD TV, its 2 million pixels are packed so densely that the image appears completely smooth.³¹⁴ On a larger HD set, say 55 inches (more than double the area of a 36-inch screen), individual pixels may be discernible depending on the viewing distance. 4K video on a 55-inch screen may be completely smooth, but on a 65-inch screen (1.17 m², 40% larger than a 55-inch screen) individual pixels may start to become visible. On an 85-inch (1.99 m²) or 100-inch (2.76 m²) screen, only 8K content, native or upscaled, may guarantee a completely smooth image.

Figure 17: 8K's higher pixel density becomes more important as screen size increases

Average selling price of 8K panels, 2017–2022, worldwide



Screen size (diagonal, inches)	55	65	75	85	110
Screen area (m ²)	0.83	1.17	1.55	1.99	3.34
Pixels per inch, 8K	160	136	118	104	80
Pixels per inch, 4K	80	68	59	52	40

Source: Deloitte analysis.

The sheer size of an 80-inch or larger TV set might appear to be a disincentive to purchase, as it would be too large to fit in most people's cars. But online ordering and delivery are ready solutions for this. In the first half of 2019, one-quarter of all TV sets sold globally were bought online; in China, this figure was 50%.³¹⁵ Lockdown is likely to have accelerated the move to online TV sales, even if research took place in physical stores.

Surmounting the comparison hurdle

Many studies have examined consumers' ability to tell an 8K image apart from a 4K one. These studies tend to suggest that differentiating between the two is hard, with capability varying by genre of content. Nature documentaries appear to benefit most from 8K, perhaps because of the greater range of natural colors that can be displayed with the standard.

However, the inability to tell 4K from 8K may not matter in the long run. What matters more may be that owners of 8K TV sets enjoy—and derive utility from—the knowledge that their flat panel is capable of showing images in 8K. This phenomenon recognizes that the consumer is not always rational. The rise of the 4K format occurred while most content was available only in HD, and the rise of HD happened while standard-definition content prevailed. Even today, moviegoers may only know that they are watching in 4K if a trailer tells them so: They are not readily able to tell the difference.

The rise of the 4K format occurred while most content was available only in HD, and the rise of HD happened while standard-definition content prevailed.

The popularity of 8K TV sets is likely to be boosted by the appeal of very large panels of 75 inches and larger. The larger the TV set, the more immersive the experience. The television is steadily but inexorably transitioning from being the bulky cube in the corner to the slender panel occupying ever larger expanses of wall in ever more intense and vivid colors. 8K and very large panels are likely to become regarded by consumers as one and the same, regardless of the underlying resolution of the content. This is likely to drive satisfaction among owners and envy among visitors to friends' 8K-equipped living rooms.

8K's production end

Though this chapter has focused mostly on the drivers for consumers to adopt 8K, we should also consider the incentives and barriers to creating content in 8K.

8K film and television cameras have existed for more than five years. Red, one of the first companies in the market, launched its first 8K camera in 2015.³¹⁶ However, little content has been created in 8K to date. One reason for this is because few 8K TV cameras have been commercially sold: For much of the last decade, only prototypes were available. Additionally, shooting in 8K entails considerable incremental costs, such as for additional storage—one hour of raw 8K footage requires more than seven terabytes, or about 122GB per minute, of storage space—as well as for new monitors and cables.

That said, creating content in 8K also has several advantages that may balance out these current drawbacks. One of these advantages is that shooting in 8K may allow for better quality in postproduction. Downsampling 8K video to 4K often delivers a cleaner overall image than footage originally captured in 4K. This approach also eliminates certain types of artifacts in the final image,³¹⁷ and may also help with image stabilization, which requires zooming in up to 20%.³¹⁸ 8K capture for 4K masters is likely to be particularly useful for movies with many visual effects (VFX), whose images can be subject to significant postprocessing.³¹⁹

Reframing from higher-resolution images is also easier in 8K. Crops at 4K resolution can be readily created from an 8K file without loss of resolution, delivering smaller pixels and more detail.³²⁰ For sports, shooting in 8K enables fast-moving subjects from runners to racing cars to be more easily framed in 4K. Indeed, 8K cameras, whose prices as of summer 2020 started from US\$4,000, may even change how sports photography is done.³²¹ Sports photographers have traditionally relied on ever-faster SLR cameras capable of shooting multiple frames per second, with the hope that one of the hundreds of photos taken will be the money shot. With 8K video, the photographer can film the action at the highest resolution, then pull off a single frame, which will be 33MP in size. Nature documentary makers, whose subjects may move as unpredictably as footballers around a pitch or boxers in a ring, can also benefit from 8K video to generate high-definition stills.³²² The cost of creating in 12K to be able to downsample to 8K now starts at US\$10,000, with the launch of Blackmagic's 12K camera in the summer of 2020.³²³

Sports photographers have traditionally relied on ever-faster SLR cameras capable of shooting multiple frames per second, with the hope that one of the hundreds of photos taken will be the money shot.

Finally, shooting in 8K extends the period in which content could be monetized. Content that is shot in 8K and mastered to 4K for release in 2021 could be rereleased in 8K in subsequent years as more 8K screens become available. This is important because the lifetime of content can be measured in decades. For instance, *I Love Lucy*, which first aired in 1951, was filmed in 35mm,³²⁴ enabling remastered versions to be created from the original recordings many years later. An HD remaster of *I Love Lucy* on Blu-ray was released in 2014.³²⁵

Beyond the consumer to commercial environments

Most 8K content created or remastered in 2021 is likely to be targeted to consumers for consumption at home. But a growing volume of 8K content is also likely to be created for commercial uses such as:

- **Retail displays.** Video displays have long been a major weapon for attracting and selling to customers in physical retail. As retail recovers from lockdown, 8K screens are likely to become an increasingly important differentiator, used both to lure customers into a store and to market products and brands. For retail installations, 8K screens can be built from modular panels, and they can also be attached to curved surfaces. They do not need to be 16:9 rectangles.
- **Advertising panels.** 8K is likely to become increasingly important for outdoor and instore panels due to its higher resolution and greater color range.
- **Trade shows.** Presenters at trade shows need to compete relentlessly for attention. 8K screens, bespoke or based on standard panels, can be one way of attracting visitors to a stand, continuing a decades-long trend of screens being a principal way to draw in potential customers.

- **Live events.** Concerts are designed to be spectacular, and a major element in this are the vast, bespoke screens that serve as a backdrop to musicians. Major concerts featuring 8K walls are likely to become increasingly common once live events are able to resume safely. One of the first bands to use an 8K screen was U2, whose 2017 Joshua Tree tour featured a five-story (14-meter) 8K screen that stretched the 61-meter width of the stage, alternatively showing high-resolution visuals and live images of the band. Other stars to feature 8K screens in their concerts include Taylor Swift and Lady Gaga.³²⁶
- **Office space.** Reception areas give visitors their first impression of a company. 8K screens can be used in these areas to showcase a company's messaging, such as its brand values. Larger companies may be able to readily afford the cost of premium 8K panels costing tens of thousands of dollars.³²⁷

8K's implications for adjacent industries

8K's spread among consumers can create opportunities for adjacent industries, with the

telecommunications industry in particular standing to benefit. Operators should consider 8K TV sets as an opportunity to market higher-speed connections. They could bundle their highest-speed connections—1 gigabit per second (Gbit/s) in many markets—with subscription video on demand (SVOD) services offering 8K content, pairing the highest picture quality with the best broadband connections. However, operators should not expect gains in revenue from increased network traffic just yet. In 2021, 8K is unlikely to have a significant impact on network traffic overall, not only due to the still-niche installed base of 8K sets, but also because most content shown on 8K-capable panels is likely to be in lower resolution.

For their part, SVOD providers offering content in 8K may be able to bundle this content as part of a premium package. They will incur additional costs for storing and delivering higher-resolution content, but some of these should be recoupable by charging a premium for 8K content, as many pay TV (including SVOD) operators already do for 4K and (in some markets) HD content.

Content that is shot in 8K and mastered to 4K for release in 2021 could be rereleased in 8K in subsequent years as more 8K screens become available. This is important because the lifetime of content can be measured in decades.

The bottom line

Ultimately, 8K's core attraction to consumers is as an option on the future of video, and it will appeal to buyers for emotional as well as rational reasons. Owning an 8K screen offers the prospect of enjoying movies and television programming in the best possible quality in terms of pixel density, color range, screen brightness, and sound. It opens up the possibility of showing next-generation 8K video games on the best available screen. It also gives consumers the option of using large TV sets in new ways. They will no longer be just for watching video content, but also could be used to display digital wallpaper or, for home workers, productivity tools.

Commentators should not dismiss 8K's prospects on the grounds of irrationality. Similar arguments were made about 4K: The screens would be too big for rooms, viewers would be seated too close or too far from the screen, or few would be able to discern the difference between HD and 4K. These resoundingly logical objections do not appear to have held sway. The majority of new TV buyers will opt for 4K in 2021, and they are likely to increasingly opt for 8K over the coming years.

For virtually all consumers today, a television set is a necessary fixture of everyday life. A few households will, of course, prioritize bookshelves over TV girth, but these may well be increasingly rare. Besides 8K's appeal in terms of video and sound quality, the mass market is likely to relish a screen that dominates and defines a room rather than one hidden in a corner, and many will be eager to claim the bragging rights of owning the latest, largest state-of-the-art TV set. 8K televisions are eminently suitable for all these purposes—and this will position them to invade the TV market in 2021 and beyond.



From virtual to reality

Digital reality headsets in enterprise and education

How can a company train workers to unload hazardous materials, configure a wind turbine, or service a jet engine when a pandemic makes it impossible to teach and learn these skills in person?³²⁸ One way to do it is to use virtual reality (VR), augmented reality (AR), and mixed reality (MR) to simulate those environments

for workers to practice in. We predict that, led by purchases by corporations and educational institutions, sales for enterprise and educational use of wearable headsets for VR, AR, and MR—collectively known as XR or digital reality—will grow by 100% in 2021 over 2019 levels.

Overall spending on AR and VR headsets, software, and services, including purchases by consumers, rose in 2020 to US\$12 billion globally, up 50% from 2019.³²⁹ Although this figure is lower than the prepandemic forecast of almost 80% growth, it was much better than worldwide IT spending, which declined by more than 5% for 2020 year over year.³³⁰ Postpandemic, higher growth is expected to resume for XR, with one group predicting the industry will reach a total of US\$73 billion in 2024, or a 54% annual growth rate between 2020 and 2024.³³¹

Although the predicted growth rate in headsets specifically is off a low base, with fewer than 100,000 VR, AR, and MR headsets purchased annually by enterprises and schools from 2015 through 2019, the upward trend appears clear. Market growth for these types of headsets has already accelerated in some markets due to the risk of COVID-19 infection driving their use in teaching employees and students virtually rather than in person. With the pandemic accelerating the opportunity to demonstrate their value, digital reality headsets may continue to gain ground after the pandemic ends due to a variety of other benefits, such as lower cost, greater safety, and better learning retention.

XR's pivot to the enterprise market

Within the total XR industry, enterprise applications such as training and industrial maintenance were predicted to generate US\$1.3 billion and US\$0.4 billion in 2020, respectively.³³² These numbers are still smaller than consumer sales—but over the next few years, organizational purchases of XR will likely narrow the gap, with all of the fastest-growing digital reality markets expected to be in enterprise or education. Sales of XR for use in public infrastructure maintenance, industrial maintenance, and logistics and package delivery management are predicted to more than

double every year from 2019 to 2024. And both post-secondary and K-12 lab and field spending on digital reality is expected to rise more than 120% annually over the same period.³³³

It may be surprising that organizational XR sales are expected to gain ground on those to consumers, especially in a time of pandemic when consumers might have flocked to VR headsets to alleviate the boredom of being locked down at home. (The consumer headset market is almost entirely for VR headsets, with AR and MR being primarily enterprise devices.) In tech blogger Ben Evans' memorable phrase, pandemic lockdowns were a kind of "forced experiment" for various technologies—including work-from-home tools, online grocery delivery, and home entertainment setups for gaming and video streaming—and VR seems a natural technology for consumers to add to the mix.³³⁴ But although consumer VR did not collapse in 2020, neither did it surge. To quote Ben Evans again: "This should have been a [consumer] VR moment, and it isn't."³³⁵ Consumers bought about US\$2.9 billion worth of VR headsets in 2020, down 12% from US\$3.3 billion in 2019, though sales are expected to rebound to US\$3.5 billion in 2021.³³⁶ That 2020 decline is better than what happened to cinema attendance during the COVID-19 lockdowns, which were down 66% worldwide for the year.³³⁷ But it is less good than game console sales, which were up 150% annually in March 2020 as billions of people confined to their homes sought ways to entertain themselves.³³⁸

Given lower-than-hoped-for growth in the consumer market, XR headset makers have been shifting to the enterprise. The first AR headset, Google Glass, was originally intended for the consumer market at its release in 2014, but it was relaunched in 2017 in a pivot to the enterprise market³³⁹. In April of 2020, Magic Leap announced that it too had decided to pursue enterprises

as its primary market.³⁴⁰ Microsoft's HoloLens has always been targeted at the enterprise, not the consumer. Even consumer VR companies such as Facebook-owned Oculus and HTC started enterprise divisions in 2019.³⁴¹ There are rumors that Apple may launch AR and VR products in 2021—likely mainly for the consumer at first, but they may also have enterprise and education applications over time.³⁴²

Headsets, of course, are only part of a complete XR package. Adding up all the spending on enterprise XR, it is likely that the enterprise digital reality market generated revenues of US\$13 billion in 2019, up 19% from the prior year. This number is larger than the total XR market mentioned earlier, as it includes internal R&D, which is large at this stage of the enterprise digital reality market evolution.³⁴³ Determining the unit sales and dollar value of the headset portion only, excluding software, services, and internal R&D, is a difficult task: No XR makers disclose segmented sales in dollars or units on a quarterly or annual basis. But despite this difficulty, it is still possible to glean some information from occasional announcements by headset makers, enterprises, and educational institutions, as well as from media coverage.

Why aren't enterprise and education headset sales higher?

Between 2015 and 2020, there were dozens of different public announcements regarding enterprise and education digital reality. Deloitte Global has analyzed these public announcements and found some important trends.

Headsets are shared technology, not personal

Although some enterprise technology tools such as the PC and the smartphone are personal (one per employee), other tools such as printers and LED projectors are shared among many employees: Tens or hundreds of employees use the

same device as needed, and for only a brief period of time per use. The latter pattern of use is emerging as typical for XR headsets. For instance, in 2018, Walmart obtained 17,000 Oculus Go entry-level VR headsets, sending four units to all of its supercenters and two units to smaller locations. Using these 17,000 headsets, the company was able to train over a million employees on more than 45 different modules about new technology, customer service/empathy, and compliance. On average, almost 60 employees used each headset.³⁴⁴

Not every employee may need a headset

It may be obvious that some types of workers, such as office workers, have little need for XR headsets. But even in jobs where digital reality headsets might be useful, not every employee may require one. One of the more common uses for XR headsets in the workplace is to onboard new hires only, rather than using them to support existing employees.

Not every location needs headsets

The Canadian province of Saskatchewan has 1.2 million residents, 40% of whom live in remote areas. It has deployed two pairs of Google AR headsets in each of 11 communities so that onsite medical practitioners can consult in real time with experts in urban medical centers. The tool has proved “invaluable for wound treatment,” according to Ivar Mendez, unified head of the Department of Surgery at the University of Saskatchewan.³⁴⁵ But as useful as digital reality headsets can be in remote areas, they are not needed for such applications in urban areas, where a majority of the world's population lives.

Headsets may be only a small part of a project's total cost

The costliest publicly announced XR project to date is the 2018 US\$480 million deal between the United States Army and Microsoft using the MR HoloLens.³⁴⁶ This agreement was not for off-the-shelf

headsets, but for customized devices with thermal sensing and night vision used not just for training but on the battlefield as well. Although there have been discussions of follow-on orders for 40,219 headsets costing over US\$2 billion over several years,³⁴⁷ the initial deal covered only 2,500 headsets over two years. Even if these headsets cost 10 times more than off-the-shelf HoloLens units, or about US\$30,000 each, the total hardware value of 2,500 headsets would be a mere US\$75 million. In other words, the software, services, and development portions of the overall MR solution likely represented more than five-sixths of the total contract value, and the headsets themselves only about 16%.

Digital reality headsets are still in their early days, and are mostly used in pilots

More than half of the public announcements concerning XR headsets include the words “pilot,” “trial,” or “test.” The training, enterprise, and education market for headsets is still relatively nascent, and it is therefore not surprising that individual companies and schools have only bought tens or hundreds of units. That said, as the Walmart and US Army stories illustrate, follow-on purchases can be on the order of tens of thousands of units.

Putting all of that together, the headset markets that are moving fastest right now are in immersive training, especially where real-world training would be dangerous, difficult, or expensive; for frontline health care workers;³⁴⁸ for use in retail (consumer-facing, but still an enterprise use case); and for building digital reality strategies across the domains of hardware, software, and services.

What about education?

As mentioned earlier, the market for educational XR is poised to be among the fastest-growing XR segments over the next few years. Admittedly, this growth is off a very small base. Educational uses of digital reality have been embryonic between 2015 and 2020; according to one report, the global education XR market was only US\$0.68 billion in 2019,³⁴⁹ and the headset component of that (as distinct from software, content, and services) is likely less than US\$100 million. Our research on headset announcements and partners uncovered no large education-specific pilots. Some small pilots do exist, but these use only a few headsets. For example, Brock University in Canada was using VR in classrooms prior to the pandemic, but it only has six headsets.³⁵⁰

That said, as schools and colleges have been shut down due to the pandemic, XR and XR headsets are proving a valuable tool. As one example, a Canadian postsecondary institution is using VR for welding and automotive painting vocational programs, and has found the technology so useful and safe that it “will likely continue to use it when COVID-19 restrictions ease.”³⁵¹ And one university in Kentucky has been teaching classes during the pandemic with HTC Vive VR headsets (although it has only 18 of them).³⁵² Other schools in California, Michigan, and Mexico also use a variety of digital reality headsets for MBAs and other programs.³⁵³

The bottom line

As enterprise and education XR headset sales grow, it is worth keeping in mind that these sales are likely to continue to represent a minority of total digital reality project spend compared to software, development, content, and services. Over time, however, the hardware component will likely grow as a percentage of project value, as many of the other costs tend to be upfront while headsets become more material as pilots turn into full deployments.

What could boost enterprise headset sales even more would be if they follow the same trajectory as several other workplace devices. In the 1980s, some businesses had a single portable computer or radiotelephone/cellular phone for communal use. Over time, these devices became seen as so useful that every employee had to have their own, and price points dropped so significantly that doing so became affordable. A similar shift in both perceived utility and price for digital reality headsets could increase the market by 10 times or more.

It is unclear how XR headsets will fare postpandemic. It is possible that some of the enterprise and education use of digital reality headsets will be a blip: The headsets will be used during lockdown periods, and then discarded when things return to normal. However, for most organizations, it seems more likely that the COVID-19 period will be a crucible in which XR headsets prove their usefulness, spurring continuing growth. After all, if it's too dangerous, too difficult, or too expensive to train in the real world, why wouldn't you train in a virtual one?

Price will be one important factor spurring growth. It is anticipated that both existing manufacturers and new entrants will introduce high-quality digital reality headsets under the magic US\$1,000 price point. Other reasons to anticipate increase in the use of digital reality include:

- Hard numbers on some enterprise VR programs so far show that they improve productivity by an average of 32%.³⁵⁴
- Academic research suggests that AR is better than video in workplace settings. Employees prefer it, their problem-solving improves, they make fewer errors, and they perceive it as more efficient than a standard video call.³⁵⁵
- AR training yields a 75% learning retention rate, higher than almost any other form of training. (Lectures and reading have only a 5%–10% retention rate.)³⁵⁶ Another study showed that AR results in greater knowledge transfer and more than doubles learning outcomes.³⁵⁷
- VR appeals to a variety of learning styles,³⁵⁸ and is especially useful for training that requires repetition and retention.³⁵⁹
- For learning in dangerous environments (such as for firefighters), VR is safer and less risky for employees and students.³⁶⁰

With VR, people do not need to travel to access training devices, and they do not need to bring heavy equipment to a special training location.³⁶¹

If it's too dangerous, too difficult, or too expensive to train in the real world, why wouldn't you train in a virtual one?

Companies and educational institutions looking to deploy XR can consider several best practices:³⁶²

- **Make it impactful.** XR is about business outcomes and ROI, not about building shiny objects. Digital reality should solve problems in ways that were not otherwise possible.
- **Make it engaging.** Technology for technology's sake isn't helpful to anyone. It has to fit into the way humans work in order to achieve better outcomes.
- **Make it flexible and scalable.** A well-designed solution is built to evolve with new developments in the technology.
- **Make it work with change management.** XR is going to have far-reaching effects on workplaces and schools in the years to come, which will require new ways of working and thinking.
- **Make it easy.** Digital reality headsets should be more plug-and-play than they are now, especially for consumers, but also for enterprise and education.
- **Make it physically attractive.** Many early XR headsets were too large, uncomfortable, or ungainly. Physical appeal matters even more for the consumer market, but it applies to both enterprise and education markets too.

Not all work and learning are suitable for XR—for example, to receive fine-grained tactile feedback when practicing surgery or delicate mechanical operations. Yet the future may see advances in haptics as the technology further develops.³⁶³ And as it does, we can expect digital reality to become more widespread among businesses and educational institutions alike, transforming the way we get the job—or the learning—done.

Endnotes

01. <https://www.weforum.org/agenda/2020/05/covid-19-taking-gaming-and-esports-next-level/>
02. Deloitte analysis
03. Frost & Sullivan
04. Deloitte analysis
05. Deloitte analysis
06. Online gaming: How the pandemic has shaped the future of e-gaming in India | The Financial Express
07. <https://www.itv-asia.com/en/articles/3657-the-state-of-mobile-insights-into-emerging-behaviors-on-mobile-devices>
08. Online gaming industry in India is expected to grow at a CAGR of 47% by FY22: Study - The Financial Express
09. <https://financesonline.com/number-of-gamers-worldwide/>
10. India Among Top 5 Countries In Online Mobile Gaming: Report - Inc42 Media | Flurry analytics
11. https://www.thedmti.com/wp-content/uploads/2019/03/India_Mobile_Marketing_Handbook_2019.pdf
12. <https://knowledge.wharton.upenn.edu/article/indias-demographic-dividend-asset-or-liability/>
13. <http://cmrindia.com/the-future-of-mobile-gaming-is-female-cmr/>
14. ICEA report: 83 crore smartphone users by 2022 | Technology News, The Indian Express
15. Internet: India has over 500 mn active Internet users, 14% of 5-11 yrs: IAMAI - The Economic Times (indiatimes.com)
16. EIU report | India
17. <https://www.rbi.org.in/Scripts/PublicationsView.aspx?id=18992>
18. <https://www.orfonline.org/research/covid-19-and-indias-media-and-entertainment-sector-recommendations-for-recovery-67249/>
19. <https://www.newsbytesapp.com/news/business/upi-records-over-two-billion-transactions-in-october/story#:~:text=NPCI%2C%20which%20manages%20UPI%2C%20said,jump%20of%2015%25%20from%20September.>
20. Online gaming: How the pandemic has shaped the future of e-gaming in India | The Financial Express
21. Gaming Industry - Size, Growth, Trends, Forecasts (2020 - 2025) - mordorintelligence.com
22. Investing in India's Online Gaming Sector: Growth Trends Amid COVID-19 - India-briefing.com
23. <https://agbbrief.com/headline/real-money-games-in-india-next-big-segment/>
24. <https://www.deccanchronicle.com/technology/in-other-news/110316/desi-card-games-rule-the-digital-gaming-industry-in-india.html>
25. <https://startuptalky.com/growth-of-gaming-industry/>
26. <https://www.limelight.com/resources/white-paper/state-of-online-gaming-2020/>
27. <http://www.ficci.in/ficci-in-news-page.asp?nid=21022>
28. <https://www.imgglobalinfotech.com/blog/fantasy-sports-market-size-india>
29. Online gaming: How the pandemic has shaped the future of e-gaming in India | The Financial Express
30. <https://www.financialexpress.com/brandwagon/how-online-gaming-industry-attracted-money-and-eyeballs-in-2020-rakes-in-173-million-in-investments/2149199/>
31. <https://www.financialexpress.com/brandwagon/how-online-gaming-industry-attracted-money-and-eyeballs-in-2020-rakes-in-173-million-in-investments/2149199/>
32. <https://www.hindustantimes.com/brand-stories/2020-the-up-and-coming-year-for-indian-gaming-industry/story-FZdh2XYuCVmXF5DoomuovK.html>
33. <https://www.hindustantimes.com/brand-stories/2020-the-up-and-coming-year-for-indian-gaming-industry/story-FZdh2XYuCVmXF5DoomuovK.html>
34. Reliance Jio Leads Series A Funding Of Mobile Gaming Start-up Krikey - inc42.com
35. Animation, gaming critical for job creation; I&B Ministry working on policy' (livemint.com)
36. Online gaming: Education Ministry looks to tap massive job opportunity for students | Jobs News - India TV
37. The Power of Mobile Gaming in India, MMA and Kantar IMRB in association POKKT
38. <https://icea.org.in/wp-content/uploads/2020/07/Contribution-of-Smartphones-to-Digital-Governance->

- in-India-09072020.pdf
39. <https://www.financialexpress.com/brandwagon/how-online-gaming-industry-attracted-money-and-eyeballs-in-2020-rakes-in-173-million-in-investments/2149199/>
 40. Deloitte analysis
 41. Charles McLellan, "Edge computing: the state of the next IT transformation," ZDNet, October 1, 2018.
 42. This estimate is based on 3rd party market research and Deloitte's own evaluations. For this evaluation, the market includes hardware, edge networks, applications, and services that directly serve demand for edge computing and intelligence. Given the broad nature of the market, these estimates may be more directional than precise.
 43. Robert Clark, "Telcos need to get in shape for the rush to the edge," LightReading, September 17, 2020.
 44. Patrick Moorhead, "It's official- NVIDIA acquires Arm For \$40 billion to create what could be a computing juggernaut," Forbes, September 13, 2020.
 45. Klaus Schwab, "The Fourth Industrial Revolution: what it means, how to respond," World Economic Forum, January 14, 2016.
 46. George Leopold, "Edge computing seen transitioning to 'intelligent edge,'" Enterprise AI, September 10, 2020.
 47. Patrick Moorehead, "It's official – NVIDIA acquires Arm for \$40 billion to create what could be a computing juggernaut."
 48. Mark Casey, Jeff Loucks, Duncan Stewart, and Craig Wigginton, Bringing AI to the device: Edge AI chips come into their own, Deloitte Insights, December 9, 2019.
 49. Ken Carroll and Mahesh Chandramouli, Scaling IoT to meet enterprise needs, Deloitte Insights, June 20, 2019.
 50. Ibid.
 51. Chris Arkenberg, Naima Hoque Essing, Sanket S. Nesargi, and Jeff Loucks, Unbundling the cloud with the intelligent edge: How edge computing, AI, and advanced connectivity are enabling enterprises to become more responsive to a fast-moving world, Deloitte Insights, September 8, 2020.
 52. Rafael Calderon, Amit Sinha, Ednilson Bernardes, and Thorsten Wuest, "Digital supply networks," Deloitte, July 2020.
 53. John McCormick, "California utilities hope drones, AI will lower risk of future wildfires," Wall Street Journal, September 11, 2020.
 54. Charlotte Jee, "Boston Dynamics' dog robot Spot is going to patrol an oil rig in Norway," MIT Technology Review, February 13, 2020.
 55. Technology Business Research, Inc., "Telecom edge compute market landscape," June 11, 2019.
 56. Dr. Song Jun, "Challenges & key issues of constructing 'MEC-ready' 5G bearer networks for carriers," telecoms.com, January 20, 2020.
 57. Pablo Valerio, "To comply with GDPR, most data should remain at the edge," IoT Times, October 31, 2018.
 58. Sam Schechner and Emily Glazer, "Ireland to order Facebook to stop sending user data to U.S.," Wall Street Journal, September 9, 2020.
 59. Aaron Tilley, "A cloud surge lifts Amazon, Microsoft, and Google's results," Wall Street Journal, July 31, 2020.
 60. Mike Robuck, "Verizon and IBM take their talents to the enterprise edge with IoT and 5G," Fierce Telecom, July 16, 2020.
 61. Mike Dano, "SBA, American Tower double down on edge computing opportunity," LightReading, August 4, 2020.
 62. Rich Miller, "The AWS cloud extends to the edge, with likely boost for colo providers," Data Center Frontier, December 20, 2019.
 63. Technology Business Research, Inc., "Webscale ICT market landscape," Third Calendar Quarter, 2019.
 64. Chris Arkenberg, Mark Casey, and Craig Wigginton, Coming to a CDN near you: videos, games, and much, much more, Deloitte Insights, December 9, 2019.
 65. Matthew Prince, "The edge computing opportunity: it's not what you think," The Cloudflare Blog, July 26, 2020.
 66. Preeti Wadhvani and Saloni Gankar, "Edge data center market size worth over \$20 billion by 2026," Global Market Insights, press release, October 5, 2020.
 67. Paul Gillin, "How three wireless technologies will soon ignite the edge computing revolution," SiliconANGLE, January 26, 2020.

68. Casey, Loucks, Stewart, and Wigginton, Bringing AI to the device: Edge AI chips come into their own.
69. Patrick Moorhead, "Intel quietly becoming a player on the 'edge'," Forbes, April 13, 2020.
70. Don Clark, "Nvidia buys Arm from SoftBank for \$40 billion," New York Times, September 13, 2020.
71. Mike Robuck, "Report: Despite Covid-19 disruption in 2020, data center capex poised to hit more than \$200B over next five years," Fierce Telecom, July 24, 2020.
72. Pete Bartolik, "Edge computing frameworks abound—with none yet dominant," IoT World Today, January 14, 2020.
73. <https://nasscom.in/knowledge-center/publications/iot-india-next-big-wave>
74. Deloitte analysis of publicly available information (e.g., press releases, company websites, and industry newsletters); analysis may combine multiple deployments in the same country and may not be exhaustive.
75. Dell'Oro Group, "Open RAN market expected to eclipse \$5B," press release, September 1, 2020.
76. Matt Kapko, "Open RAN set to capture 10% of market by 2025," SDxCentral, September 2, 2020.
77. Ken Wieland, "5G gives RAN market a Q1 boost—Dell'Oro," Light Reading, May 15, 2020.
78. Thomas Seal, "Huawei Barometer' shows political pressure on 5G rollout: Map," Bloomberg, September 4, 2020.
79. Open RAN enables the relocation of the BBU from the cell site to a virtualized central (CU) or distributed (DU) data center.
80. Iain Gillott, "Open RAN integration: Run with it," iGR, April 2020.
81. Pongratz, "Industry voices—Pongratz: Virtualized and open RAN gain momentum," Fierce Wireless, March 6, 2020.
82. CTIA, The state of wireless, 2018.
83. Higher integration costs are discussed later in this article.
84. Open RAN Policy Coalition, "5G and open RAN security: Next generation trust," June 2020.
85. To push much of the traditional function of the core network out to the RAN edge network, Rakuten had to spend considerable time and energy in creating an entirely new automated operations support system (OSS), working closely with software developers to translate and enrich IT workload management techniques to meet carrier-grade requirements.
86. A recent survey on Connectivity and Mobile Trends highlights that consumers care most about network reliability and availability from their provider. See Kevin Westcott et al., Build it and they will embrace it, Deloitte Insights, 2019.
87. Claudio Coletti et al., "O-RAN: Towards an open and smart RAN," O-RAN Alliance, October 2018.
88. Dell'Oro Group, "RAN market returned to growth in 1Q 2020," press release, May 15, 2020.
89. Bevin Fletcher, "FCC 'stuns' RWA with immediate USF ban on Huawei," Fierce Wireless, July 1, 2020.
90. The 3rd Generation Partnership Project (3GPP) is a standards organization which develops protocols for mobile telephony.
91. Jamie Davies, "GSMA cosies up to O-RAN Alliance," Telecoms, May 29, 2020.
92. Martijn Rasser and Ainikki Riikonen, "Open future: The way forward on 5G," Center for a New American Security, July 28, 2020.
93. Ibid.
94. Rakuten convinced Nokia to open its optical networking and radio equipment to enable open RAN in exchange for revenue associated with managing and maintaining the Phase 1 build out.
95. Eugina Jordan, "Open RAN 101—Integration and beyond: Why, what, when, how?," RCR Wireless News, July 23, 2020.
96. Matt Kapko, "How Rakuten Mobile corralled vendors for its open RAN vision," SDxCentral, May 5, 2020.
97. Gabriel Brown, "The outlook for 5G open vRAN," Light Reading, May 11, 2020.
98. Ibid.
99. Kapko, "How Rakuten Mobile corralled vendors for its open RAN vision."
100. Ray Le Maistre, "DISH commits to open RAN for US 5G rollout, enters retail mobile market," Telecom TV, July 1, 2020.
101. Matt Kapko, "Telefonica wades into open RAN across global footprint," SDxCentral, March 18, 2020.
102. Intel spokesperson citing Dell'Oro Jan 2020 report, Telecom TV presentation, June 23, 2020.

103. TRAI Archive
104. Deloitte Analysis
105. Deloitte Analysis
106. Deloitte Analysis
107. Benjamin Mueller, "Telemedicine arrives in the U.K.: '10 years of change in one week,'" New York Times, April 4, 2020.
108. Assistant Secretary for Planning and Evaluation, "Medicare beneficiary use of telehealth visits: Early data from the start of the COVID-19 pandemic," July 28, 2020.
109. Office of Public and Intergovernmental Affairs, "VA Video Connect visits increase 1000% during COVID-19 pandemic," U.S. Department of Veterans Affairs, June 12, 2020.
110. Connexion, "Covid-19 sparks rise in online GP services in France," March 6, 2020.
111. Amina Zafar, "Many Canadians used virtual medical care during COVID-19, poll suggests," CBC, June 8, 2020.
112. Daily Chronicle, "Astonishing growth in telehealth virtual visits market which is growing exponentially with the major key players in the market within the forecast period 2020-2027," August 28, 2020.
113. Kavita Joshi and Onkar Sumant, Home and medical equipment market, Allied Market Research, March 2020.
114. Mueller, "Telemedicine arrives in the U.K."
115. Ibid.
116. Jill J. Ashman, Pinyao Rui, and Titilayo Okeyode, "Characteristics of office-based physician visits, 2016," NCHS Data Brief No. 331, Centers of Disease Control and Prevention, January 2019.
117. Lancaster University, "Why some older people are rejecting digital technologies," Science Daily, March 12, 2018.
118. Pew Research Center, "Internet/broadband fact sheet," June 12, 2019.
119. Federal Communications Commission, 2019 Broadband deployment report, May 29, 2019.
120. Karen Taylor, Bill Hall, and Sara Siegel, Digital transformation: Shaping the future of European Healthcare, Deloitte, September 2020.
121. Alex Schulte, Melissa Majerol, and Jessica Nadler, Narrowing the rural-urban health divide: Bringing virtual health to rural communities, Deloitte Insights, November 27, 2019.
122. David Jarvis, Mark Casey, and Craig Wigginton, High speed from low orbit: A broadband revolution or a bunch of space junk?—TMT Predictions 2020, Deloitte Insights, December 9, 2019.
123. AT&T Business, "5 ways 5G will transform healthcare: Improving patient experience with personalized, preventative care," accessed September 28, 2020.
124. Sukhbir Cheema, "Video calling is the 'new normal' and it's all because of coronavirus," Mashable SE Asia, accessed September 28, 2020.
125. Howard S. Friedman, "Nonverbal communication between patients and medical practitioners," Journal of Social Sciences 35, no. 1 (1979): pp. 82–99.
126. "This indicator presents data on the number of consultations patients have with doctors in a given year. Consultations with doctors can take place in doctors' offices or clinics, in hospital outpatient departments, or, in some cases, in patients' own homes. Consultations with doctors refer to the number of contacts with physicians, both generalists and specialists. There are variations across countries in the coverage of different types of consultations, notably in outpatient departments of hospitals. The data come from administrative sources or surveys, depending on the country. This indicator is measured per capita." See: OECD, "Data: Doctors' consultations," accessed September 28, 2020.
127. The weighted average cost is weighted by the number of annual visits per country times the price per visit paid in that country.
128. The World Bank, "GDP (current US\$)," accessed September 28, 2020.
129. OECD, "OECD health statistics 2020," July 1, 2020.
130. OECD, "Primary care," accessed September 28, 2020.
131. The Commonwealth Fund, "Average annual number of physician visits per capita, 2017," accessed September 28, 2020.

132. Edward Worthington, "The future of telehealth and telemedicine," Alpha Sense, accessed September 28, 2020.
133. Klick Health, "Patients prefer physicians who offer telemedicine during COVID-19 and beyond, says new Everyday Health and Klick Health research," August 6, 2020.
134. Jake DiBattista, "Is there a real time advantage to telemedicine?," MiraMed, accessed September 28, 2020.
135. Brooke LeVasseur, "How telehealth and econsults are reducing patient wait times," Patient Safety & Quality Healthcare, November 14, 2019.
136. Jacob E. Simmering et al., "Are well-child visits a risk factor for subsequent influenza-like illness visits?," Infection Control and Hospital Epidemiology 35, no. 3 (2014): pp. 251–6.
137. David Betts, Leslie Korenda, and Shane Giuliani, Are consumers already living the future of health? Key trends in agency, virtual health, remote monitoring, and data-sharing, Deloitte Insights, August 13, 2020.
138. Worthington, "The future of telehealth and telemedicine."
139. Bill Fera, Casey Korba, and Maulesh Shukla, The future of virtual health: Executives see industrywide investments on the horizon, Deloitte Insights, April 30, 2020.
140. StartUp Health, "StartUp Health's 2020 midyear funding report shows a robust, diversified health innovation market," July 1, 2020.
141. Tom Murphy, "Telemedicine provider Teladoc to spend \$18.5B on Livongo," Associated Press, August 5, 2020.
142. GlobalData, "Wearable tech market set to grow 137% by 2024 but smartwatches to see a 10% decline in revenue this year due to shipment delays and tighter consumer wallets, says GlobalData," August 13, 2020.
143. Alexandro Pando, "Wearable health technologies and their impact on the health industry," Forbes, May 2, 2019.
144. Mark Terry, "Apple Watch atrial fibrillation study has high rate of false positives," Bio Space, March 18, 2019. Apple Watch is a trademark of Apple Inc., registered in the United States and other countries. TMT Predictions 2021 is an independent publication and has not been authorized, sponsored, or otherwise approved by Apple Inc.
145. Indian Brand Equity Foundation (IBEF), "Indian Healthcare Industry Analysis", December 4, 2020 (article link: <https://www.ibef.org/industry/healthcare-presentation>)
146. Indian Brand Equity Foundation (IBEF), "Indian Healthcare Industry Analysis", December 4, 2020 (article link : <https://www.ibef.org/industry/healthcare-presentation>)
147. Central Bureau of Health Intelligence (CBHI), "National Health Policy - 2019 (14th Issue)", November 2019 (article link : https://cddep.org/wp-content/uploads/2020/04/State-wise-estimates-of-current-beds-and-ventilators_24Apr2020.pdf)
148. The Center for Disease Dynamics, Economic Policy (CDDEP) and Princeton University, "Covid-19 in India: State-wise estimates of current hospitals beds, intensive care unit (ICU) beds and ventilators", April 20, 2020
149. The Hindu - Business Line by Radheshyam Jadhav, "52% of India's Allopathic doctors are practicing in just 5 states", April 2, 2020 (article link: <https://www.thehindubusinessline.com/news/52-of-indias-allopathic-doctors-are-practising-in-just-5-states/article31227994.ece>)
150. Times of India by Kanav Kahol, "Telemedicine: The next technology frontier in the healthcare ecosystem in India", August 21, 2020 (article link: <https://www.expresshealthcare.in/news/eight-indian-digital-health-companies-received-40-million-in-vc-funds-in-q3-2020/425334/>)
151. Inc42Plus, "The Future of Edtech in India", October 8, 2020
152. ASSOCHAM India and Sathguru, "Digital transformation of Indian healthcare", September 2020
153. Healthcare Apps Market in India 2019 – research report from ResearchAndMarkets.com, accessed on 06 Jan 2021 (article link: <https://www.businesswire.com/news/home/20200221005384/en/Healthcare-Apps-Market-in-India-to-Generate-a-Value-of-138-Billion-in-2024-from-27.01-Billion-in-2019--ResearchAndMarkets.com#:~:text=In%20terms%20of%20revenue%2C%20the,during%20the%202019%2D2024%20period>)

154. Indian Ministry of Health and Family Welfare along with NITI Aayog, "Telemedicine Practice Guidelines", March 20, 2020.
155. Jared Spataro, "2 years of digital transformation in 2 months," Microsoft, April 30, 2020. The cloud growth figures in the first two paragraphs are from Deloitte's analysis of publicly reported quarterly financial statements.
156. Wikipedia, "Cloud computing," accessed November 4, 2020.
157. International Data Corporation, "IDC expects 2021 to be the year of multi-cloud as global COVID-19 pandemic reaffirms critical need for business agility," March 31, 2020.
158. Business Wire, "Infrastructure and security challenges threaten multi-cloud and edge deployments, new survey from Volterra shows," March 9, 2020.
159. Wikipedia, "Replication crisis," accessed November 4, 2020.
160. Eric Jhonsa, "Public clouds are bright spot as IT outlays slow due to virus," The Street, April 3, 2020.
161. Deloitte analysis of publicly reported quarterly financial statements.
162. Synergy Research Group, "Hyperscale data center count reaches 541 in mid-2020; another 176 in the pipeline," Globe Newswire, July 7, 2020.
163. Deloitte analysis of publicly reported quarterly financial statements.
164. Sandvine, COVID internet phenomena spotlight report, accessed November 4, 2020. In the previous paragraph, the semiconductor growth figures are from Deloitte's analysis of publicly reported quarterly financial statements.
165. Farhan Ahmad, "FQ3 2020 financial results," Micron, June 29, 2020.
166. ETF Database, "Cloud computing ETF list," accessed November 4, 2020.
167. James Bourne, "2020 to be a 'bumper year' for data centre M&A—amid Covid-19—as value surpasses 2019 total," Cloud Tech, April 24, 2020.
168. Dave Vellante, "Cloud computing market remains strong, but it's not immune to COVID-19," SiliconANGLE, August 15, 2020.
169. Benedict Evans, "COVID and forced experiments," April 13, 2020.
170. SightsIn Plus, "Siemens to let staff 'Work From Anywhere' permanently," July 17, 2020.
171. Deloitte analysis of publicly reported quarterly financial statements.
172. Ibid.
173. IMARC Group, "Global anything-as-a-service market to reach US\$ 344.3 billion by 2024, organizations undergoing digital transformation facilitating growth," press release, accessed November 4, 2020.
174. Deloitte, "XaaS models: Our offerings," accessed November 4, 2020.
175. Synergy Research Group, "Hyperscale operator spending on data centers up 11% in 2019 despite only modest capex growth," March 24, 2020.
176. Stephanie Condon, "Google expands its Cloud AI portfolio," ZD Net, September 1, 2020.
177. Mike Miliard, "Hasty rush to cloud hosting during COVID-19 crisis could set stage for 'cyberpandemic'," Healthcare IT News, June 30, 2020.
178. Chris Arkenberg et al., "Unbundling the cloud with the intelligent edge: How edge computing, AI, and advanced connectivity are enabling enterprises to become more responsive to a fast-moving world," Deloitte Insights, September 8, 2020.
179. Kelly Hill, "Google Cloud jumps into 5G and telco edge computing with a 'GMEC' vision," RCR Wireless News, March 5, 2020.
180. Deloitte, Cloud migration, 2019.
181. Blackhat, Cyber threats in turbulent times, accessed November 4, 2020.
182. David Linthicum, "COVID-19 leads to shocking cloud computing bills," InfoWorld, July 31, 2020.
183. Mike Chan, "How to calculate the true cost cloud migration," Network World, February 2, 2017.
184. Deloitte, "Cloud value calculator," accessed November 4, 2020.
185. Deloitte, In times like these you learn to love the cloud, accessed November 4, 2020.
186. Gillian Crossan et al., Accelerating agility with XaaS: Many companies are using IT as-a-service to steer their way to competitive advantage, Deloitte Insights, 2018.
187. Beena Ammanath, Susanne Hupfer, and David Jarvis, Thriving in the era of pervasive AI: Deloitte's State of AI in the Enterprise, 3rd edition, Deloitte Insights, 2020.

188. CB Bhattacharya, "How the great COVID-19 reset can help firms build a sustainable future," World Economic Forum, May 15, 2020.
189. OECD, "Building back better: A sustainable, resilient recovery after COVID-19," June 5, 2020.
190. Steve Lohr, "Cloud computing is not the energy hog that had been feared," New York Times, February 27, 2020.
191. NRDC, "Is cloud computing always greener?," issue brief, October 2012.
192. Netflix used 451,000 megawatt hours to deliver video in 2019, and Netflix viewers consumed about 112 billion hours during the year. See: Netflix, Environmental social governance, 2019; Elsa Keslassy, "Netflix's Cindy Holland says subscribers watch an average of two hours a day," Variety, March 11, 2019.
193. Rich Miller, "Data bytes: Cloud CapEx, PUE trends, HPC spending, servers on the edge," Data Center Frontier, August 3, 2020.
194. OpenAI, "AI and compute," May 16, 2018.
195. Will Knight, "AI can do great things—if it does not burn the planet," Wired, January 21, 2020.
196. Saif M. Khan Alexander Mann, AI chips: What they are and why they matter, Center for Security and Emerging Technology, p. 18.
197. Deloitte, Hitting the accelerator: The next generation of machine-learning chips, 2017.
198. Khan and Mann, AI chips, p. 23.
199. Nvidia, Nvidia AI Inference platform, 2018.
200. Paul Lee et al. Technology, Media, and Telecommunications Predictions 2020, Deloitte Insights, 2019.
201. Thomas Lorensen, "Arm Cortex-M55 and Ethos-U55 processors: Extending the performance of Arm's ML portfolio for endpoint devices," Arm Community, February 10, 2010.
202. Wikipedia, "Television transmitter," accessed November 3, 2020.
203. PCS Electronics, "HQ FM/TV transmitter superstore: How to start guide," accessed November 3, 2020.
204. For more information on small cells, see Safi Khan, "The backbone of 5G networks: A guide to small cell technology," Telit, March 12, 2020.
205. Very small base stations are also known as femtocells. Larger base stations are picocells, microcells, and macrocells. With each generation of cellular technology, base station equipment has become progressively smaller.
206. Rod Panter, "Electromagnetic radiation from TV and mobile phone towers: Health aspects," Current Issues Brief 26, Parliament of Australia, 1996–97. For the previous statement that television transmitters have been delivering content wirelessly for more than 100 years, see Wikipedia, "History of radio," accessed November 20, 2020. The first radio broadcasts started in November 1919, in The Hague, Netherlands.
207. Ken Karipidis et al., "Mobile phone use and incidence of brain tumour histological types, grading or anatomical location: A population-based ecological study," BMJ Open 8, no. 12 (2019).
208. For more information on the methodology, and for a more detailed review of the conclusions, see A. Keykhosravi et al., "Radiation effects of mobile phones and tablets on the skin: A systematic review," Advances in Medicine, April 2018.
209. Media Arts and Technology, "The cell phone technology," accessed November 30, 2020.
210. Christer Törnevik, "Impact of EMF limits on 5G network roll-out," Ericsson, December 5, 2017.
211. Kurt Behnke, "Is this anything to worry about? 5G health issues explained," Grandmetric, March 26, 2019; Kenneth R. Foster, Sachiko Kodera, and Akimasa Hirata, "5G communications systems and radiofrequency exposure limits," IEEE Future Networks Tech Focus 3, no. 2 (2019).
212. Ericsson, "Base stations and networks," accessed November 3, 2020. It is important to note that there are two metrics for measuring power output: the effective radiated power (ERP) and the actual radiated power. An ERP of 100 watts would be equivalent to about 5–10 watts actual radiated power. See, US Federal Communications Commission, "Human exposure to radio frequency fields: Guidelines for cellular antenna sites," October 15, 2019.
213. Behnke, "Is this anything to worry about?"
214. Ericsson, "Base stations and networks."
215. Behnke, "Is this anything to worry about?"
216. According to the WHO, this is because the frequencies used for FM transmission and TV are typically

lower than for mobile telephony, that is at around 100 MHz, 300 MHz–400 MHz, and 900–1800 MHz and up respectively. See World Health Organization, “Electromagnetic fields and public health,” accessed November 3, 2020.

217. Science Direct, “Transmitter power,” accessed November 3, 2020.
218. Ibid.
219. Wikipedia, “History of television,” accessed November 3, 2020.
220. Wikipedia, “History of radio,” accessed November 3, 2020.
221. EMF Explained, “Welcome to the EMF explained series,” accessed November 3, 2020.
222. Dexter Johnson, “The 5G dilemma: More base stations, more antennas—less energy?,” *IEEE Spectrum*, October 3, 2018.
223. Beamforming is also known as massive MIMO; Ericsson, “Radio waves and health: 5G,” accessed November 3, 2020.
224. National Institute of Standards and Technology, “High-power lasers for manufacturing,” accessed November 3, 2020.
225. Ofcom, “Electromagnetic Field (EMF) measurements near 5G mobile phone base stations,” February 21, 2020.
226. Full Fact, “5G is not accelerating the spread of the new coronavirus,” March 31, 2020.
227. Wasim Ahmed et al., “Four experts investigate how the 5G coronavirus conspiracy theory began,” *The Conversation*, June 11, 2020.
228. Ofcom, “COVID-19 news and information: Summary of views about misinformation,” July 7, 2020.
229. Data from week three of the Ofcom weekly survey of news consumption among UK consumers, fielded between April 10–12, 2020. For more information, see Ofcom, “COVID-19 news and information: Consumption and attitudes,” April 21, 2020.
230. Ben Cohen, Jared Diamond, and Andrew Beaton, “The decade when numbers broke sports,” *Wall Street Journal*, December 19, 2019.
231. Oura Health, “Oura partners with WNBA for 2020 season,” press release, Business Wire, July 30, 2020; Nicole Wetsman, “There’s unproven tech in the NBA’s COVID-19 prevention plan,” *Verge*, July 31, 2020; Andrew Cohen, “NBA offers players smart rings to search for signs of COVID-19,” *SportTechie*, June 18, 2020.
232. Jessica Golden, “PGA Tour procures 1,000 smart bands to help detect coronavirus symptoms in golfers,” *CNBC*, June 24, 2020; Will Ahmed, “Podcast No. 80: Pro golfer Nick Watney on how WHOOP warned him of COVID-19,” *Whoop*, June 27, 2020.
233. Jessica Golden, “Here’s the device the NFL and NBA are using for coronavirus contact tracing and social distancing,” *CNBC*, July 21, 2020; KINEXON, “How KINEXON technology contributes to the restart in German professional sports,” June 8, 2020.
234. Michael Long, “Sports tech investment: Where are the venture capitalists spending their money?,” *SportsPro*, January 30, 2020.
235. NFL OPS, “NFL next gen stats,” accessed August 31, 2020.
236. Laine Higgins, “Big data is coming to the National Hockey League,” *Wall Street Journal*, October 10, 2019.
237. Niall Seewang, “Why Australia leads sports world in wearable technology,” *ESPN*, June 15, 2016.
238. Darren Rovell, “MLB approves device to measure biometrics of players,” *ESPN*, March 6, 2017.
239. Taylor Bloom, “Major League Baseball will now allow players to use two specific wearables during games,” *SportTechie*, April 6, 2016.
240. Scott Riewald (senior director for high-performance projects, United States Olympic and Paralympic Committee), interview with authors, August 20, 2020.
241. Ibid.
242. Northwestern University, “Rogers Research Group,” accessed August 31, 2020.
243. Riewald interview.
244. Ibid.
245. Eben Harrell, “How 1% performance improvements led to Olympic gold,” *Harvard Business Review*, October 30, 2015.
246. Joe Lemire, “Scouting in the NFL may never be the same,” *SportTechie*, April 22, 2020.

247. Joe Lemire, "Wimu Pro wearable grows to all levels of elite Mexican soccer," SportTechie, June 6, 2019.
248. Teresa M. Walker and Larry Fenn, "AP analysis: NFL teams lost over \$500M to injuries in 2019," Associated Press, January 29, 2020.
249. Andrew Beaton, "The NFL wants to better predict injuries," Wall Street Journal, December 5, 2019.
250. PSA, "New biometric data suggests squash could be world's toughest racket sport," April 6, 2018.
251. Mary Bates, "The rise of biometrics in sports," IEEE Pulse, June 29, 2020.
252. KINEXON, "KINEXON and Content Stadium transform real-time data to real-time content," October 14, 2019.
253. Mark Van Deusen, "Empowering players with data ownership," Whoop, April 28, 2017.
254. NBA, "NBA announces sports betting partnership with William Hill," press release, October 2, 2019; PGA TOUR, "DraftKings becomes PGA TOUR's first official betting operator," July 28, 2020.
255. Darren Rovell, "Alliance of American Football will have enhanced in-game betting," ESPN, September 10, 2018.
256. Women's National Basketball Association, Collective bargaining agreement, January 17, 2020.
257. Brian Costa and Jared Diamond, "The downside of baseball's data revolution—long games, less action," Wall Street Journal, October 3, 2017.
258. NFL, Collective bargaining agreement, 2020.
259. NBA, Collective bargaining agreement, January 19, 2017.
260. David Ornstein, "Players to sue for hundreds of millions over use of their statistics," The Athletic, July 26, 2020.
261. Globe Newswire, "Global sports betting market size & share will reach USD 155.49 billion By 2024: Zion Market Research," August 29, 2019.
262. Brent Kendall, Chris Kirkham, and Andrew Beaton, "Supreme Court ruling for New Jersey opens door to sports betting," Wall Street Journal, May 14, 2018.
263. Brant James, "Biometrics: Currency, conundrum in sports betting future," Gambling.com, November 30, 2018.
264. Jacob Gershman, "The brave new world of betting on athletes' data," Wall Street Journal, March 10, 2020.
265. Deloitte estimates based on various sources including The Korea Bizwire, "8K TV war intensifies but consumers still prefer 4K," October 24, 2019; Display Supply Chain Consultants, "Samsung extends lead in advanced TV shipments in Q2," August 3, 2020.
266. In the term "8K," K refers to one thousand, and the naming is based on the approximate number of horizontal lines, which is 7,680. The total number of pixels is derived from multiplying the number of horizontal lines by the vertical lines.
267. 4K is a reference to the number of horizontal lines, rounded up to the nearest thousand. There are 3,840 horizontal lines on a 4K screen and 2,160 vertical lines.
268. Sharp, "8K UHD reality will overwhelm you," accessed September 4, 2020.
269. The audio specification splits sound into 24 separate channels, spread across 22 speakers and two subwoofers. However, as few homes are likely to have 24 speakers, 8K video is likely also to be offered in 5.1 sound, which is allocated to six speakers. See NHK STR, "22.2 multichannel audio format standardization activity," 2011.
270. The majority of content is likely to be filmed in HD or SD (high definition, standard definition). A small proportion of content will be filmed in 4K.
271. For more information on one test undertaken, see Scott Wilkinson, "8K vs 4K TVs: Double-blind study by Warner Bros. et al reveals most consumers can't tell the difference," TechHive, February 28, 2020.
272. HD Report, "List of 4k/HDR/Atmos movies and TV shows on Netflix," accessed September 29, 2020. For the previous statement on a TV's expected lifespan, see Alexis C. Madrigal, "The new laws of TV upgrading," Atlantic, January 6, 2012; Lee Neikirk, "How long should your TV last?," Reviewed.com, February 13, 2019; Erin Lawrence, "When should I upgrade my TV?," Best Buy Blog, September 20, 2020.
273. Samsung Newsroom, "All in' on AI, part 2: Driving the evolution of 8K picture quality and advanced sound on TV through AI," February 14, 2018.
274. Michael Hicks, "Here's the secret behind 8K AI upscaling technology," TechRadar, August 26, 2019.

275. Samsung Newsroom, "[The future of viewing] QLED 8K: Where AI upscaling meets deep learning," April 3, 2020.
276. For an explanation of how upscaling was applied on the first 4K TVs, and why this sometimes delivered suboptimal images, see Hicks, "Here's the secret behind 8K AI upscaling technology."
277. Jeff Baumgartner, "Putting the squeeze on 8K," Light Reading, May 19, 2020.
278. Ibid.
279. Gavin J. Blair, "Japan's NHK launches world's first 8K TV channel," Hollywood Reporter, January 4, 2019.
280. My Fair Lady had already been scanned into 8K a few years back in order to create a 4K version. The 8K version created for 8K broadcast was based on the existing archived scan. See Carolyn Giardina, "'My Fair Lady' gets 8K restoration," Hollywood Reporter, March 8, 2019.
281. Display Daily, "Production of 8K content for 8K TVs," accessed November 5, 2020.
282. Jacob Kastrenakes, "Netflix had House of Cards' third season made in 6K," The Verge, March 10, 2015.
283. Matt Mulcahey, "DP Erik Messerschmidt on shooting Netflix's Mindhunter with a custom red Xenomorph," Filmmaker Magazine, October 26, 2017.
284. There are also a few devices with 64-megapixel and 108-megapixel capabilities that may output photos as 12 megapixels by compressing nine pixels into one. For more information, see Sam Byford, "Why Samsung's 108-megapixel camera isn't just a gimmick," The Verge, February 12, 2020; Sam Byford, "Do 64-megapixel phone cameras really make a difference?," The Verge, October 1, 2019.
285. Richard Bennett, "The best 8K phones in 2020," Wondershare, October 20, 2020.
286. Jamie Carter and James Artaius, "What is 8K? And what does it mean to photographers and videomakers?," Digital Camera World, July 7, 2020.
287. Rasmus Larsen, "YouTube now streaming 8K video on 8K TVs with AV1 support," FlatpanelsHD, May 8, 2020.
288. Vimeo, "Videos tagged '8k,'" accessed September 23, 2020.
289. Geoffrey Morrison, "PS5 and Xbox Series X can game in 8K resolution. Should you care?," CNET, October 29, 2020.
290. Consoles will use SSD to enable much faster loading of games content. See Chaim Gartenberg, "Sony reveals full PS5 hardware specifications," The Verge, March 18, 2020.
291. Ibid.
292. Charlie Noon, "1080p vs. 4K gaming: Is gaming at 4K worth it?," WePC, October 28, 2020.
293. For example, Apple Fitness+ enables data from the Apple Watch wrist wearable device to be displayed on a television set via the Apple TV digital media extender. See Apple, "Apple Fitness+," accessed September 23, 2020. TMT Predictions 2021 is an independent publication and has not been authorized, sponsored, or otherwise approved by Apple Inc.
294. Amazon Fire TV, "All 182 screensavers on your Amazon Fire TV and their locations (photos)," June 16, 2017; Benjamin Mayo, "Apple TV now features 10 beautiful underwater video screensavers," 9to5Mac, September 25, 2019. TMT Predictions 2021 is an independent publication and has not been authorized, sponsored, or otherwise approved by Apple Inc.
295. For example, see Loupe, accessed September 23, 2020.
296. GfK, "4K is becoming the standard for today's TVs," press release, September 4, 2019.
297. The Korea Bizwire, "8K TV war intensifies but consumers still prefer 4K."
298. Ibid.
299. Ibid.
300. 8K TV sets first went on sale in the last quarter of 2017. See GfK, "4K is becoming the standard for today's TVs."
301. Advanced Television, "IHS: Over half of Q4 TV shipments were UHD," March 7, 2019.
302. Chris Chinnock, "Yes, you really can see 8K in your future," Information Display, November 28, 2019.
303. GfK, "4K is becoming the standard for today's TVs."
304. Danielle Cassagnol, "Consumer tech U.S. sales to reach record \$422 billion in 2020; streaming services spending soars, says CTA," Consumer Technology Association, press release, January 5, 2020.
305. GfK, "Global smartphone sales reached \$522 billion in 2018," press release, February 22, 2019.
306. Gartner, "Gartner forecasts worldwide device shipments to decline 14% in 2020 due to coronavirus impact," press release, May 26, 2020.

307. Mike Snider, "Despite coronavirus pandemic, consumers still turned on by big-screen TVs," USA Today, July 20, 2020.
308. Jörn Krieger, "Corona crisis drives TV set sales in Germany," Broadband TV News, July 21, 2020.
309. A further type of business model would be to offer the TV set on a subscription basis, with the cost depending on the specification of the TV, and the quantity of advertising viewed.
310. Advanced Television, "IHS: Over half of Q4 TV shipments were UHD."
311. David Katzmaier, "Remember when TVs weighed 200 pounds? A look back at TV trends over the years," CNET, July 26, 2020.
312. Jon Porter, "65-inch TVs are now the most popular choice for North American households: Report," The Verge, July 5, 2019.
313. Snider, "Despite coronavirus pandemic, consumers still turned on by big-screen TVs."
314. For more information on pixel density, see Tim Fisher, "How many pixels in an inch (PPI)?," Lifewire, May 5, 2020.
315. GfK, "4K is becoming the standard for today's TVs."
316. Jon Silberg, "8K ecosystem is ready for implementation," TV Technology, April 20, 2020.
317. Display Daily, "Production of 8K content for 8K TVs."
318. Steve May, "Why 8K is transforming movies, and why you probably haven't noticed yet...," Home Cinema Choice, June 19, 2020.
319. Silberg, "8K ecosystem is ready for implementation."
320. Ibid.
321. James Artaius, "Sharp 8K video camera—still alive, still under \$4,000, due second half 2020," Digital Camera World, January 14, 2020.
322. Carter and Artaius, "What is 8K? And what does it mean to photographers and videomakers?."
323. Chris George, "Wow! Blackmagic 12K camera makes stunning entrance (and the price is amazing too)," Digital Camera World, July 17, 2020.
324. Leigh Allen, "Filming the I Love Lucy show," American Cinematographer, April 1, 2020.
325. Gordon S. Miller, "I Love Lucy: Ultimate season 1," High-Def Digest, May 7, 2014.
326. Stephen Armstrong, "Inside the Amish town that builds U2, Lady Gaga, and Taylor Swift's live shows," Wired, January 5, 2018.
327. Amrita Khalid, "The world doesn't need 8K TV—yet," Quartz, January 24, 2020.
328. Tony DeMarinis et al., Real learning in a virtual world: How VR can improve learning and training outcomes, Deloitte Insights, August 14, 2018.
329. IDC, "Worldwide spending on augmented and virtual reality forecast to deliver strong growth through 2024, according to a new IDC spending guide," November 17, 2020.
330. Gartner, "Gartner says worldwide IT spending to grow 4% in 2021," press release, October 20, 2020.
331. IDC, "Worldwide spending on augmented and virtual reality forecast to deliver strong growth through 2024."
332. Ibid.
333. Ibid.
334. Benedict Evans, "COVID and forced experiments," April 13, 2020. For the previous statement about the consumer headset market being almost entirely for VR devices, see Jeremy Horwitz, "What's next for consumer AR in 2020," VentureBeat, December 26, 2019.
335. Benedict Evans, "The VR winter," May 9, 2020.
336. SuperData, "SuperData XR Q3 2020 update," October 28, 2020.
337. Georg Szalai, "Global cinema revenue to drop 66 percent in 2020 amid pandemic: Forecast," Hollywood Reporter, September 3, 2020.
338. Christopher Dring, "What is happening with video game sales during coronavirus," GamesIndustry.biz, March 31, 2020.
339. Jay Kothari, "A new chapter for Glass," X blog, July 18, 2017.
340. Rony Abovitz, "Charting a new course," Magic Leap, April 22, 2020.
341. Charlie Fink, "HTC doubles down with Vive VR Enterprise Solutions," Forbes, July 1, 2019; Oculus, "Introducing the new Oculus for business," April 30, 2019.

342. MacRumors, "Apple glasses," October 22, 2020. TMT Predictions 2021 is an independent publication and has not been authorized, sponsored, or otherwise approved by Apple Inc.
343. SuperData, "XR will save enterprise \$13.5 billion in training costs," February 13, 2019.
344. Jane Incao, "How VR is transforming the way we train associates," Walmart, September 20, 2018.
345. John Dujay, "Google Glass returns as workplace tool," Canadian HR Reporter, February 1, 2018.
346. Makena Kelly, "Microsoft secures \$480 million HoloLens contract from US Army," The Verge, November 28, 2018.
347. Todd South, "The Army wants to buy 40,000 'mixed reality' goggles," ArmyTimes, February 11, 2020.
348. Jeremy Horwitz, "NHS finds VR training boosts coronavirus frontline worker performance," VentureBeat, June 17, 2020.
349. Technavio, "COVID-19 impacts: Virtual reality market in education sector will accelerate at a CAGR of over 59% through 2020–2024," Business Wire, August 7, 2020.
350. Maryanne St. Denis, "Brock prof to enhance online learning with 3D classroom," The BrockNews, July 18, 2019.
351. Denise Ryan, "COVID-19: Trades schools are thriving in the new normal," Vancouver Sun, June 7, 2020.
352. Alicia Kelso, "How one UofL class turned to virtual reality during COVID-19," UofL News, July 13, 2020.
353. VirBELA, "VirBELA use cases," accessed November 4, 2020.
354. Magid Abraham and Marco Annunziata, "Augmented reality is already improving worker performance," Harvard Business Review, March 13, 2017.
355. XMReality, "Field study shows that remote guidance using augmented reality (AR) is more effective than a standard video call," press release, October 30, 2018.
356. Bobby Carlton, VR Learn: Virtual reality and learning, Elliott Masie, January 2017.
357. Johannes Moskaliuk, Johanna Bertram, and Ulrike Cress, "Impact of virtual training environments on the acquisition and transfer of knowledge," Cyberpsychology, Behavior, and Social Networking 16, no. 3 (2013).
358. Pixo, "How virtual reality suits different learning styles," October 21, 2019.
359. DeMarinis et al., Real learning in a virtual world.
360. US Fire Administration, "Virtual reality training may save firefighter lives," July 8, 2020.
361. Dieter Holger, "How businesses are cutting employee training costs with VR," VR Scout, March 17, 2018.
362. Henrik Ebbesen and Claus Machholdt, "Digital reality changes everything," Deloitte Digital, accessed November 4, 2020.
363. Sophie Bushwick, "New virtual reality interface enables 'touch' across long distances," Scientific American, November 20, 2019.

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