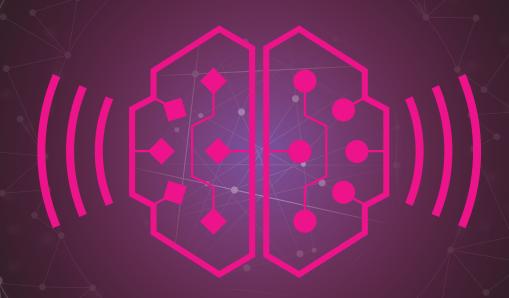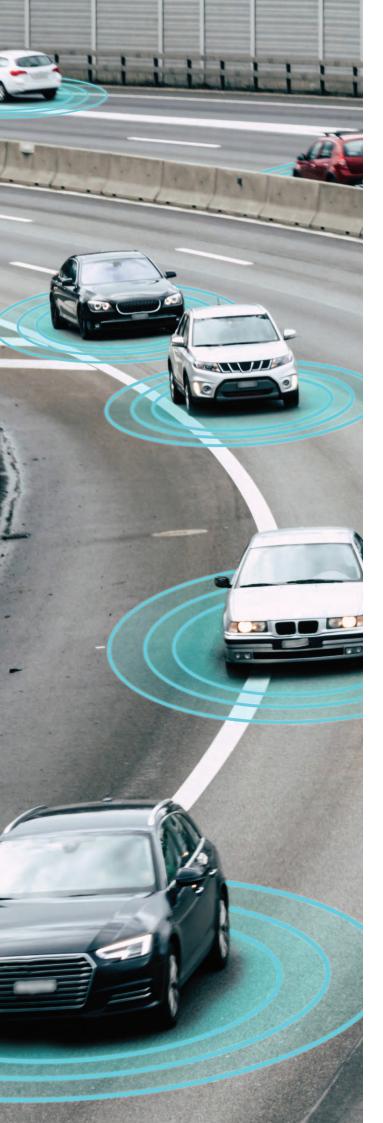# INTELLIGENT CONNECTIVITY

HOW THE COMBINATION OF 5G, AI, BIG DATA AND IOT IS SET TO CHANGE EVERYTHING

FOREWORD

The combination of 5G, artificial intelligence (AI), smart platforms and the Internet of Things (IoT) form the basis of what we call 'Intelligent Connectivity'. With more than 5.1 billion unique subscribers and nearly 9 billion connections globally, mobile is already one of the most widely deployed technology platforms ever. However, Intelligent Connectivity takes this further and marks the beginning of an era of highly contextualised and personalised experiences, underpinned by ubiquitous hyper connectivity. It is set to impact almost every aspect of our daily lives from the way we consume entertainment to the way in which we learn and interact with colleagues. It will give people the information they need in an instant making our lives more productive and efficient. It will impact how entire industries innovate and operate, how societies interact and thrive and how economies flourish.

We will watch live sports coverage in ultra-high definition via Augmented or Virtual Reality headsets and see the game from an athlete's perspective; our cities will deploy traffic control systems that use 5G connectivity to instruct vehicles when to slow down and when to accelerate removing the need for traffic lights and speed cameras. We will see smart platforms powered by (AI) and machine learning will enable us to make improved decisions and deliver higher quality products and services.

5G is already on the way with commercial launches expected this year in the United States, China, South Korea and the UAE. GSMA Intelligence forecasts that there will be more than 1.3 billion 5G connections globally by 2025, covering 40% of the global population. 5G networks will underpin this revolution. It is an opportunity to create an agile, purpose-built network tailored to the different needs of citizens and the economy. It will improve network capacity, throughput and responsiveness. However, it is imperative that all stakeholders work together to ensure that 5G is successfully standardised, regulated and brought to market.

Underpinned by hyper connectivity and low power wide area IoT networks, the fusion of these groundbreaking technologies will change everything, improving our lives in many different ways and intelligently connecting everyone and everything to better future.

Foreword by Mats Granryd
Director General,
GSMA

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EXECUTIVE SUMMARY

The potent combination of 5G, artificial intelligence, smart platforms and the Internet of Things will change the world. Drawing on interviews with mobile operators, investors and analysts, this report describes some of the exciting services and experiences that could be enabled by intelligent connectivity:

Entertainment gets rich and social - With 5G, digital entertainment is set become both richer and more social. High-speed wireless connectivity will deliver 4K and 8K video, holograms, augmented reality and virtual reality applications for gaming and immersive TV, while bringing people together to enjoy live events, such as sports and concerts. 5G could enable spectators to enjoy a 360-degree view from anywhere in the venue.

Safe and swift transportation – Vehicles and bikes will relay their position to other road users in real-time, enabling intelligent connectivity to instruct vehicles when to slow down and when to accelerate, thereby removing the need for traffic lights, speed cameras and other systems.

The dawn of Industry 4.0 - Intelligent connectivity is set to drive a fourth industrial revolution in which computers and robots continually optimise production and maintenance in highly flexible factories and plants. 5G will deliver ultra-reliable and low latency connectivity by employing edge computing and network slicing, which allows specific services to be prioritised.

Reliable remote control - In both their personal and professional lives, individuals are going to have much closer control over their assets. Tactile Internet applications will become increasingly viable, allowing for the perception and manipulation of remote objects using touch and proprioception.

Information and offers on-demand - People will have easy access to an increasingly intelligent personal assistant in the cloud, while connected glasses or contact lenses will display personalised information and offers.

Continuous health monitoring - Individuals will routinely wear connected wellness and security monitors providing continuous information about their vital signs, while enabling emergency alerts in the event of a fall or an attack. 5G will help healthcare managers to maximise the use of scarce resources and ensure that clinics don't run out of critical medicines and equipment.

Smarter and sharper security - Continuously connected cameras, sensors and alarms will make both private properties and public places more secure, while cloud-based facial recognition systems could be used identify and spot offenders in real time.

Immersive education and training - trainee engineers, mechanics and medics could learn how to perform specific tasks by following instructions relayed via AR or by using VR simulations. Similarly, 5G could enable these technologies to be used to teach science and geography students about specific habitats and environments.

Waste not, want not – Consumers and companies will have real-time information on everything from soil acidity to water pollution to the availability of parking spaces, increasing efficiency and reducing waste, while better managing energy usage.

Smarter cities and buildings - Connected sensors and actuators will give municipalities, organisations and individual citizens the ability to monitor what is happening in and around their properties and control access.

INTRODUCTION

The rollout of intelligent connectivity

The first 5G mobile networks are now being deployed, paving the way for a new era of intelligent connectivity, characterised by a dramatic expansion of the Internet of Things (IoT) and extensive use of artificial intelligence (AI). The real-world data collected by the IoT will fuel machine learning, enabling greater automation and improving decision-making. The combination of 5G, the IoT and AI will enhance the quality of products and services, drive a step-change in productivity and enable consumers and companies alike to make much more efficient use of the world's resources.

"If you are investing in tech companies, it is hard not to be excited by what intelligent connectivity will enable," says Arnie Sriskandarajah, Head of Venture Capital, Round Hill Capital.
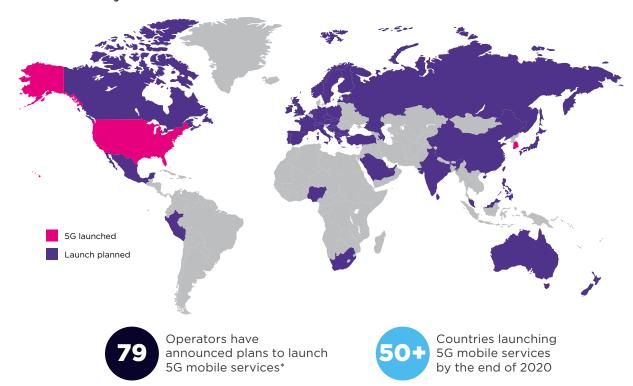
Drawing on interviews with experts from mobile operators, including Deutsche Telekom, KT Corp, Telefonica and Vodafone, and the investment community, this report describes some of the most compelling services and experiences that will be enabled by a fusion of 5G, AI and IoT.

The first 5G deployments

Worldwide, 79 mobile operators have announced plans to launch 5G services (see Figure 1). As a result, more than 50 countries are set to benefit from 5G services before the end of 2020. Vastly improving network capacity, throughput and responsiveness, 5G will enable mobile operators to tailor connectivity to the application and change daily life for the better in many different ways.

Figure 1

GSMA Intelligence forecasts there will be more than 50 5G networks worldwide by 2021

5G launched
Launch planned

79 Operators have announced plans to launch 5G mobile services*

50+ Countries launching 5G mobile services by the end of 2020

Source: GSMA Intelligence

The first 5G networks are now live in the US and South Korea. SK Telecom, KT and LG Uplus simultaneously turned on their 5G networks at midnight on 1 December 2018. Although these initial services have limited coverage and are only available for businesses using mobile routers, the Korean operators plan to offer nationwide coverage from March 2019 as 5G handsets become available. At the time of the launch, SKT said it had installed 4,100 5G base stations and plans to roll out more than 7,000 by the end of 2019, expanding coverage to 85 cities.
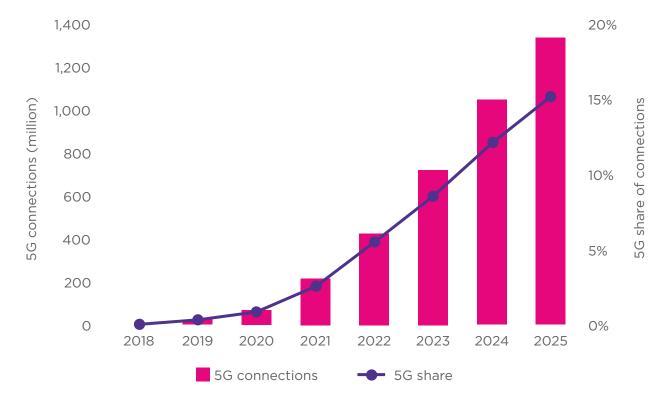
In December 2018, AT&T also announced its 5G network was live in parts of 12 cities, as it began distributing its first 5G device: the NETGEAR Nighthawk 5G Mobile Hotspot. Media reports say that AT&T has demonstrated 5G speeds of around 140 Mbps: about three times faster than a typical 4G connection. AT&T has said it will begin selling the hot spot for $499 in the spring and will offer a 5G 15GB data plan costing $70 per month. It plans to launch two Samsung 5G smartphones this year, ahead of the deployment of a nationwide mobile 5G network in early 2020. That network will allow for seamless handoffs between Wi-Fi, LTE and 5G, AT&T says. Meanwhile, Verizon is preparing a mobile 5G launch after deploying a fixed wireless access service in October 2018. For the fixed wireless service, Verizon is using 5GTF, its own proprietary standard, but plans to deploy the official 3GPP NR standard for its mobile service.

However, it could take many years for 5G to become ubiquitous. Analysts say that will require considerable investment in new infrastructure, particularly small cells, to ensure people and things can always get connected. But, there may be creative ways to share this investment. "I expect 5G and computing infrastructure to be rolled out a through a mix of public and private assets – people could be rewarded for enabling public use of their femtocell combining 5G, WiFi and local processing power," says Miles Kirby, the Managing Director of AV8 Ventures. "Cafes, restaurants and businesses will advertise that they have this infrastructure and service providers will reward them for its usage, just as buildings with solar panels can be rewarded for putting power back into the grid."

GSMA Intelligence anticipates 5G adoption will grow rapidly in the 2020s. By 2025, there could be almost 1.4 billion connections worldwide, up from about 200 million 5G connections in 2021. That would mean 5G would account for more than 15% of all mobile connections worldwide in 2025 (see Figure 2).

Figure 2

Total 5G connections will rise rapidly over the next seven years

Source: GSMA Intelligence. 5G connections excluding licensed cellular IoT and fixed wireless

New services, new experiences

Between them 4G, Wi-Fi and 5G should be able to deliver reliable, fast broadband connectivity almost everywhere and anytime. People will, quite literally, always have a broadband connection available, while download speeds of up to 1Gbps will enable a very high quality mobile Internet experience. As with 4G, 5G uses licensed spectrum, which means it isn't vulnerable to interference from other wireless signals and can provide highly secure connectivity.
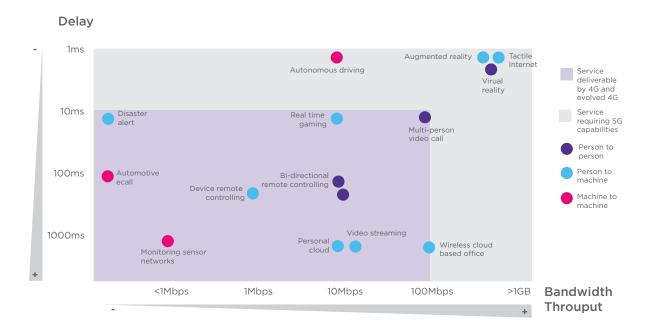
At the same time, the unprecedented responsiveness of 5G networks will enable both businesses and consumers to benefit from the so-called tactile Internet, in which people will have fingertip control over remote machines and devices. In many cases, operators will be able to all but eliminate network lag, making it straightforward for individuals to interact virtually with each other and the environment using virtual reality (VR) and augmented reality (AR). "5G will add new network capabilities to provide real-time or near-real-time services," explains Pablo Iacopino, Director of Global TMT Ecosystem Research at GSMA Intelligence. "Autonomous cars and immersive gaming will require sub-second decisions that current 4G networks are not able to provide."

Indeed, low latency connectivity will enable vehicles and other machines to respond immediately to changes in their surroundings, supporting the rollout of self-driving cars, drones and robots (see Figure 3), while enabling an array of smart city applications, including intelligent traffic management and real-time detection of crime.

As 5G evolves from theory to reality, the world's mobile operators are preparing for some profound changes in their service proposition. "We are really at an inflexion point for our industry, which will help us narrow the gap between traffic growth and ARPU growth," says Alex Choi, SVP, Research and Technology Innovation at Deutsche Telekom, explaining that the technology will open up new business models for mobile operators. "It is a kind of joint paradigm shift for computing and communications – finally they converge to produce real-time services or on-demand services. I'm sure 5G will transform the consumer lifestyle, how they interact with the world, at home, in the office and on the streets."

Figure 3

Low latency will open a range of new applications

Source: GSMA

> We are really at an inflexion point for our industry, which will help us narrow the gap between traffic growth and ARPU growth. It is a kind of joint paradigm shift for computing and communications – finally they converge to produce real-time services or on-demand services. I'm sure 5G will transform the consumer lifestyle, how they interact with the world, at home, in the office and on the streets."

Alex Choi, SVP, Research and Technology Innovation at Deutsche Telekom

Crucially, 5G is a highly flexible technology that will enable connectivity to be heavily customised for specific applications: No more one-size fits all. "The 5G network is based on virtualisation, providing a very flexible network connection," says Chaehee Kim, SVP, AI Business Unit at KT Corp. "In particular, network-slicing technology allows you to configure network components for each service attribute, thereby selecting the optimal network components for intelligent connectivity. KT will provide these technologies in the form of open APIs so that anyone can easily receive intelligent connectivity."

For Telefónica, one of the key attributes of 5G will be support for "massive IoT and hyper-connectivity in the consumer market," says Carlos Carazo Cepedano, Global IoT and Platform Technology Director. "We are each going to be surrounded by tens of connected devices. There will be plenty of data available and we will be able to build value on top of this."

The rollout of 5G is also set to be accompanied by wider adoption of edge computing – the concept of moving computing processing power closer to the end-user to boost responsiveness and reliability. Underpinned by wireless connectivity operating in licensed spectrum, edge computing should be able to deliver highly-reliable and highly-responsive services, spanning everything from cloud gaming to the coordination of drone deliveries.

Deutsche Telekom has founded a start-up, called MobiledgeX, in Silicon Valley, which has started to deliver its first product – a software platform for edge computing running on operator cloudlets. "We have decided strategically to take a lead in edge computing, which gives you lower latency services that are location-aware and context aware," says Alex Choi. "Location matters a lot and we have so many different assets, such as central offices. My vision in the longer-term is to bring computing to the cell sites. That is not going to happen yet, but this can happen. It will alleviate the traffic in the core network. There will be a move to offload last mile computing." The integration of distributed computing into highly capable and versatile cellular networks will pave the way for many of the compelling new services outlined in this report.

ENTERTAINMENT GETS RICH AND SOCIAL

With 5G, digital entertainment is set become both richer and more social. High-speed wireless connectivity will deliver 4K and 8K ultra high definition video, holograms, augmented reality (AR) and virtual reality (VR) applications for gaming and immersive TV, while bringing people together to enjoy live events. As well as supporting digital services and content in connected stadia, 5G could enable broadcasts of live sports coverage with a 360-degree view from anywhere in the venue.

"Virtual presence services will allow you to buy the very best seats at the Wimbledon tennis championships," says Miles Kirby, the Managing Director of AV8 Ventures. "You will be able to sit in the umpire's chair and look around through 360 degrees. You will be able to wander around the court and go and sit right behind Federer while he is serving."

By remotely controlling a drone, people could even take virtual day-trips or even vacations. The drone would use 5G to transmit live 360-degree images and audio from its location to a virtual reality headset worn by the user.

Although content providers are now producing VR and 3D content, the end-user devices need to become more powerful and more affordable, notes Alex Choi, SVP, Research and Technology Innovation at Deutsche Telekom. "It is not optimal yet," he notes. "But we see the silicon industry moving forward in the next three years and we will start to see mass-market devices for AR and VR. As the network operators, it is our responsibility to start to integrate these services into the end to end network. Today, AR can only support a small field of view. Some of these applications need extremely high bandwidth, requiring compression and adaptive data rates. If you are streaming 3D content live in 8K or 4K at 60 frames per second, you are going beyond 40Mbps and in some cases 100Mbps."

As the connectivity and computing improves, people will increasingly upload live, 360 degree and HD video streams, enabling friends and contacts to enjoy more immersive experiences in the moment. Although smartphones will still be widely used, 5G will have the bandwidth to deliver HD video streams to a large-screen display or even as a 3D hologram projected from a connected device. "With VR, you need an immersive experience, ideally without having to wear a wearable, like a hologram," says Phil Skipper, Head of Business Development (IoT), Vodafone. "We need to engineer out the [wearable] device."

In essence, intelligent connectivity will make it much easier for people to come together virtually to watch live sports events, music concerts or new episodes of a drama series. "Social VR is very interesting," notes Alex Choi. "You can, in effect, watch television with your friends and interact with them and chat with them. We will have a social VR demo at MWC19 Barcelona between the SKT and DT booths."

Highly immersive gaming without the expensive hardware

Gaming will become more immersive with VR, more social with multiple players and more realistic with HD graphics. Fast, responsiveness access to the Internet will enable gamers to enjoy new VR games anywhere without the cost or inconvenience of carrying specialised hardware. "Cloud-based gaming will be enhanced by 5G – you will be able to play with other people over the Internet without depending on super-fast home broadband connectivity," says Pablo Iacopino, Director of Global TMT Ecosystem Research at GSMA Intelligence. "It is not possible with current 4G networks because you need very low latency in all situations. 5G could be used for e-sports and to add an additional layer of experience at a live event."

If the computing capability moves entirely into the cloud, consumers could enjoy the latest games through lightweight 5G connected glasses. AI-assisted games platforms will tailor games and improve the experience for specific players and groups of players.

"We have partnered with the world-leading gaming company Niantic," says Alex Choi of Deutsche Telekom. "For them low latency matters a lot, as it will enable multiple players to gather together and play more immersive MMPORG[1] in AR, where they can see other players on their device screens. That is very computation-heavy and any latency matters. The gaming companies already recognise the necessity and are approaching us."

[1] *Massively multiplayer online role-playing games*

SAFE AND SWIFT TRANSPORTATION

If every road user can communicate with everything else in the vicinity, then road transport will be much safer and more efficient. Vehicles, bikes and pedestrians could relay their position to other road users in real-time, enabling AI systems to use intelligent connectivity to instruct vehicles when to slow down and when to accelerate, thereby removing the need for traffic lights, speed cameras and other systems.

SK Telecom, the largest mobile operator in South Korea, has been awarded a contract to build 5G infrastructure to support a planned intelligent transportation system in Seoul. The city's cooperative-intelligent transport system project, which is scheduled to be completed by the end of 2020, will see SKT deploy sensors and vehicle-to-everything (V2X) connectivity on major roads in Seoul. The operator will also supply 2,000 5G terminals to buses and taxis, and set up a 5G control centre for data collection and transmission of safety information. The new system, which aims to cover 121km of the city's expressways, will enable buses and taxis to communicate with bus stops and traffic lights. The Seoul Metropolitan Government will be able to analyse the data in real time, SKT said in a statement.

In the transport sector, 5G will work in conjunction with other technologies, including radar and computer vision, to make travel as safe and smooth as possible. "With autonomous cars, you will change the control mechanism depending on what infrastructure is available," notes Phil Skipper, Head of Business Development (IoT), Vodafone. "When you approach automated traffic lights, for example, the car could cede control to the infrastructure. In central London, you might rely entirely on a multi-access edge computing system, whereas on a trunk road, it might be a hybrid of mobile edge computer and cloud computer accessed via the wide area network. The crux is not the what, it is when or who makes the decision."

At the same time, 5G will help vehicles to become better at driving themselves and passengers to use their travel time productively. "Self-driving cars will rely on an on-board computer, which will be able to gather and process a huge amount of data in real-time to inform driving decisions," notes Pablo Iacopino, Director of Global TMT Ecosystem Research at GSMA Intelligence. "But 5G networks will connect autonomous cars to the wider road ecosystem or other cars and infrastructure. A lot of car manufacturers are using 4G today for early applications, but cellular V2X will need 5G to make it scalable. Autonomous driving is an important use case for 5G, early deployments are happening now, but the timeline for larger scale adoption will probably be ten years or more. As

the driver becomes a passenger, they can work in the car, or enjoy a range of entertainment services."

Chaehee Kim, SVP, AI Business Unit at KT Corp, notes that autonomous vehicles will employ AI applications that require large amounts of image processing. "These AI applications are the most efficient in high-reliability networks," she says. "For more sophisticated inference and recognition, it will be very important to return large amounts of data to the end device after very quick computation in the cloud, and 5G network will structurally support it."

Extra-sensory perception

Even before self-driving cars become mainstream, 5G will make a major difference to the motoring experience, by relaying pertinent information from roadside infrastructure and other nearby vehicles. If vehicles ahead are braking hard, the 5G connection would relay that data to the car's on-board computer, which would automatically apply its brakes. In the case of an accident, vehicles can already summon assistance without human intervention using cellular-enabled eCall services.

As drivers, cyclists and other road-users anonymously report their speed, location, trajectory, and localised atmospheric data, AI systems in the cloud can mesh this data with other road and vehicular data, including weather and surface conditions, road works and congestion, to give road-users real-time advice on their route and when to take care. To protect privacy, all road users' data needs to be anonymised and kept secure.

"Car-to-car communication will enable intelligent mobility systems which can figure out the best route to avoid congestion, to avoid pollution or determine the lowest risk route based on insurance information, depending on priority and preference." notes Miles Kirby, Managing Director at AV8 Ventures.

Making micro-mobility work

Congestion can also be tackled in other ways. In many cities around the world, so-called micro-mobility solutions designed for short journeys are gaining traction thanks to investment in cycle lanes, bike hire systems and the falling cost of electric bikes and scooters. Shared bikes and scooters can make public transport far more convenient by helping people get to and from rail stations, reducing congestion. The advent of intelligent connectivity will help service providers monitor the location and usage of shared bikes and scooters, reduce vandalism, improve safety and build sustainable business models.

[2] Direct wireless connections to computers hosted within the local roadside infrastructure.

THE DAWN OF INDUSTRY 4.0

Intelligent connectivity is set to drive a fourth industrial revolution in which robots and computers continually optimise production and maintenance in highly flexible factories and plants. The IoT, along with AI and cloud computing, is one of the key enablers of Industry 4.0. In this context, 5G will help deliver ultra-reliable and low latency connectivity by employing licensed spectrum, edge computing and network slicing, which allows specific services to be prioritised.

"The promise of 5G is that it will deliver the ultra-reliable, low latency connectivity (URLLC) that will drive a revolution for the Industrial IoT by enabling a technology to improve many use cases, such as logistics or remote control of AGVs in production plants, factories or mines," says Carlos Carazo Cepedano, Global IoT Platforms & Technology Director at Telefónica. "The intelligent connectivity will be provided by a combination of public and private networks both inside and outside the factory."

In Germany, Deutsche Telekom is running trials of private cellular campus networks with local edge computing with OSRAM, a high tech lighting manufacturer. "5G can enable the transition from analogue factories to digital factories," notes Alex Choi, SVP Research and Technology Innovation at Deutsche Telekom. "Wi-Fi was not designed from the beginning for the shop-floor: it is not sufficiently reliable or secure and it doesn't support low latency. It is not impossible to use Wi-Fi, but cellular can do the job much, much better. Wi-Fi can support connectivity for factory workers, but for advanced production capabilities, such as autonomous transport systems, you need cellular."

Equipped with edge computing, cellular networks could provide highly reliable connectivity, enabling factories to become less dependent on wires and more flexible. "A terminal is connected to an optimal edge cloud, providing ultra-low latency and high speed service," explains Chaehee Kim, SVP, AI Business Unit at KT Corp. "When users move between edge clouds, seamless service can be provided through collaboration between the edge IT cloud and the network cloud. Even if an edge cloud fails due to an unexpected event, the neighbouring edge cloud can support the service without interruption. We believe that the convergence of 5G and edge cloud will accelerate the fourth industrial revolution by expanding service through cooperation."

By capturing information in real-time and enabling remote control of machinery, factory-wide connectivity can increase efficiency and enhance the value manufacturers can provide to customers. Industry 4.0 will be characterised by self-optimising production facilities that process a continuous flow of information to automatically adapt to events, such as a supply shortage, signs of a potential machine fault or a new customer requirement. If necessary, specialist machines will be able to print 3D objects on-demand, enabling them to repair broken components.

Realising this vision will require the factory's central control system to have a detailed digital model of every asset and piece of infrastructure (a digital twin), which can be continually updated in real time. As factories become increasingly automated, they may be controlled predominantly by operators in another location. With few employees needed on-site, businesses will have more flexibility about where to locate production plants, allowing them to prioritise other factors above the availability of skilled labour.

"There is a huge endeavour within organisations to systemise the capture of data and feed it into AI and machine learning," says Ameet Shah, former Group Strategy Director at BT. "If it becomes cheap enough, I'll put connected sensors throughout a pipeline, for example. We know there is value in collecting data on how the world works. There is unlimited demand for mobile connectivity, as long as you hit the economics."

Bringing business people together

As 5G connectivity improves the quality of video calls, people will become increasingly comfortable with online business meetings and conversations. Offering lower latency and high definition video and audio transmitted in real-time, 5G will enable a video call to capture many of the subtleties and nuances of in-person meetings. Participants will be able to see immediately when someone wants to speak, and detect raised eyebrows, half smiles and other facial expressions. Moreover, individuals will be able to easily share live video of what they are looking at, enabling a technician to show colleagues a damaged component or a product manager to demonstrate a new feature.

Virtual reality headsets, virtual offices, virtual productivity tools and meeting participants represented by avatars will give people a presence in remote locations. "In the next few years, there will be a lot of things that will finally happen in the industrial space with AR and VR," concludes Christina Patsioura, Senior Analyst of Emerging Technologies at GSMA Intelligence. "For example, headsets, such as Microsoft's HoloLens, will increasingly be used by remote workers to access manuals and guidance and to visualise what a product will look like."

RELIABLE REMOTE CONTROL

In both their personal and professional lives, people are going to have much closer control over their assets. Already today, householders can use smartphone apps to remotely control their heating or their air conditioning, switch lights on or activate a washing machine. But once low latency connectivity is in place, so-called tactile Internet applications will become increasingly viable. These applications will combine haptic interaction with visual feedback, allowing for the perception and manipulation of objects using touch and proprioception - the sense of the relative positioning of the parts of one's body and the strength of effort used in movement.

With a tactile Internet connection, people could control robots performing tasks in inaccessible or inhospitable locations, such as repairing oilrigs, wind turbines and nuclear power plants. Remote operators will be able to see what the robot's on-board cameras are filming and make adjustments to the robot's actions in real-time. At an industry event in Germany in 2018, Vodafone demonstrated how a crane can now be controlled from over 350 km away in real-time.

Supplemented by edge computing, 5G could deliver the high-bandwidth, low latency and ultra-reliable connectivity required for tactile Internet applications. "For really critical applications, we will push elements down to the edge network and you could have a private network across a factory to connect your mobile edge assets," says Phil Skipper, Head of Business Development (IoT), Vodafone. "Depending on the criticality, you will re-segment the elements of control and where you put the computing power. You will be able to move elements of the control from one location to another. That will become more prevalent with 5G – you will have much more agility across platforms. With sufficient bandwidth, low latency and quality of service, the network becomes much more predictable: it becomes deterministic."

It will be 2022 or 2023 before robots can begin to show their full potential, predicts Arnie Sriskandarajah, Head of Venture Capital, Round Hill Capital. "Once we have fully cloud-connected IoT, robotics will be able to really take off," he says. "That could be a hugely valuable step change. Moving computation from on-board chips to the cloud will allow robots to work with high-bandwidth connections in open spaces as well as closed spaces. They will be operating in spaces we don't control. A lot of process-driven tasks, such as delivering food to a table or making a coffee, could be taken over by robots, but the question is to what extent will we want to interact with robots and screens, rather than human beings."

However, there will be many scenarios where there is a strong case for deploying robots instead of humans. For example, the emergency services could use robots to check burnt-out buildings at risk of collapse, while drones can scan coastlines and mountainous terrain to detect smugglers, without risks to officers.

INFORMATION AND OFFERS ON-DEMAND

Together, 5G and artificial intelligence will take the friction out of routine transactions, making it easier for buyers and sellers to find each other and do business.

Intelligent and omnipresent personal assistants

Artificial intelligence systems hosted in the cloud are developing to a point where they can understand and employ natural language to interact with humans. As a result, people will be able to query or instruct a personal assistant, regardless of where they are, via a seamless combination of 4G, 5G and Wi-Fi connectivity. Individuals might wear a 5G headset allowing them to converse with the personal assistant, which will be able to respond in milliseconds to requests for information, while handling related transactions in the background. For example, a business traveller or tourist could ask a personal assistant to find and book tables in restaurants, train tickets and hotel rooms. Already aware of the individual's preferences, the assistant would require minimal instructions.

However, it will be important to preserve individuals' privacy and maintain their trust in personal assistants. "Will need to find ways to get the benefits of understanding people's behaviours without using personally identifiable data – just extracting the useful part," says Miles Kirby, Managing Director at AV8 Ventures. "It could be that the data is processed locally and the service provider is only given the outcome. For example, an insurance company is only given a rating for how safe a driver someone is, rather than seeing all the data about where they have driven. Or it could be that you will trust the insurance company to keep that data private and not share it with third parties."

Connected glasses deliver personalised information and offers

With 5G, an individual could configure a pair of connected glasses or contact lenses to display personalised information and offers as they walk around. Depending on their immediate priorities, the user could put the glasses into navigation mode, sightseeing mode or shopping mode. Their personal assistant would then proactively deliver relevant information into a screen embedded into their connected glasses. For example, in shopping mode, a consumer passing a department store might see an offer for a pair of shoes in their size and their preferred style. Similarly, tourists could be given personalised information about a town

they are visiting so that a gourmet, for example, is given detailed descriptions and reviews of the best restaurants.

Low cost autonomous deliveries

Self-navigating, connected electric vehicles and drones could conduct last mile deliveries of pizzas, groceries and home shopping parcels. Customers will order from their mobile handset, request a delivery time and unlock the delivery cart using their handset once the item arrives. These vehicles will navigate using a 5G connection to the cloud to rapidly process data from on-board cameras and sensors. Using AI, navigation platforms will reduce delivery times and learn how to increase efficiency.

With 5G networks helping to coordinate their movements, large numbers of drones will be able to fly safely in the same locale, automatically avoiding collisions with tall buildings, street furniture and other drones. The mobile networks will provide secure connections, authentication and smart autonomous navigation, with HD video backup and a recovery location, in case something goes wrong. Cellular connectivity could also be used to support drone detection systems to help stop rogue devices from interfering with airports, power plants, prisons and other sensitive sites. "As there are no buildings or buses up in the air to interfere with signals, 3D mobile networks could be used to control drones over vast areas," notes Ameet Shah, former Group Strategy Director at BT.

The intelligent fitting room

Telefónica is working with fashion retailers to enable intelligent fitting rooms equipped with screens and sensors that provide the shopper with tailored information about the clothes that they are trying on. For example, it can highlight what other sizes the retailer has in stock and items that will match, enabling multiple use cases than involve the online channel and the business intelligence data from the customer. The clothes, tagged with RFID, will connect with 5G elements to create a real time mapping of customers and clothes inside the fitting room. In the future, these fitting rooms could become even more sophisticated. "With intelligent connectivity the screen will be able to display a moving image of you actually wearing the product," adds Carlos Carazo Cepedano, Global IoT Platforms & Technology Director at Telefónica. "You won't need to actually try it on, as the fitting room will scan your body and then use edge computing to immediately create images of you in the clothes."

CONTINUOUS HEALTH MONITORING

As 5G networks will be able to support large numbers of connections simultaneously, people will be able to routinely wear connected wellness and security monitors providing continuous information about heart rates, blood pressure, temperature, stress levels and location, while enabling emergency alerts in the event of a fall or an attack. All this information will help individuals to monitor their personal condition and take advantage of enhanced health insurance programmes, predictive healthcare and personal security solutions. Smart platforms could use machine learning to help clinicians spot patterns in medical data, enabling them to intervene earlier and help patients take preventative actions, such as changing their diet or exercising more.

For the healthcare sector, the continuous connectivity provided by 5G will help managers to maximise the use of scarce resources and help ensure that clinics don't run out of critical medicines and equipment. Today, medical expertise is still largely confined to the location of the physician, but the advent of the tactile Internet, will make it possible to get a diagnosis anywhere and at any time.

"We are already using 4G for many connected medical applications," says Phil Skipper, Head of Business Development (IoT), Vodafone. " With 5G we will be able to go to the next level for mission-critical health services: vital diagnostics, video consulting and patient monitoring will be delivered in near-real time to and from a mobile device with deterministic

performance. Our 5G Connected Ambulance in Milan is an example of this capability, leveraging 5G ultra-reliability to enable vital medical intervention on the move."

AT&T says edge computing could enable healthcare facilities to process and transfer data-intensive images between devices in the exam room, and to a doctor in near-real time. "Healthcare systems use a lot of networking power, and 5G is going to be a turning point in how mobile networks are used in caring for patients," Dr. Shafiq Rab, SVP and CIO officer, Rush University Medical Centre and the Rush System for Health, is quoted as saying in an AT&T press release. "Using multi-access edge compute (MEC), the possibility of robotics and increased telehealth are two aspects of healthcare that we're planning to explore. Ultimately, it's about creating better outcomes for our patients. 5G combined with MEC will give us the foundation to provide patients better service, and increase the quality of care we provide."

With sufficiently responsive connectivity, a physician would even be able to command a tele-robot at the patient's location, allowing remote physical examination with full audio-visual and haptic feedback. With 5G, surgeons could even carry out remote procedures using specialised robots. Although the first tele-surgical operation was carried out as early as 2001, telesurgery is still rare due to the limitations of robotics and the underlying communications technology.

SMARTER AND SHARPER SECURITY

Continuously connected cameras, sensors and alarms will make both private properties and public places more secure. The combination of 5G and AI could be used to implement instant analysis of location, video footage and any available biometric data, such as abnormal skin temperature and heart rates. Similarly, high-resolution surveillance cameras either mounted in fixed locations or worn by police officers will be able to use cloud-based facial recognition systems to identify and spot offenders in real time. For these kinds of safety or security applications, the highly reliable quality of service and coverage made possible by 5G will be crucial to ensure that these tools are available when and where they are required.

During a month-long demonstration at Haneda Airport, Samsung and the Japanese mobile phone operator KDDI used a 5G network to relay 4K images captured by video cameras and by security robots patrolling the station to a room where they could be viewed live on fixed monitors and VR goggles.

Furthermore, artificial intelligence will be able to bolster security by detecting unusual patterns of behaviour in IoT devices and act on security breaches before they become a problem for our network or for our customers business, notes Carlos Carazo Cepedano, Global IoT Platfoms &Technology Director at Telefónica. "For example, we are using AI/ML algorithms to help protect our networks from attacks by aggressive devices and so on."

In practice, most security cameras are unlikely to stream live footage to the cloud continuously. Instead, they could use a combination of local compute, edge compute and cloud compute, optimised using algorithms depending on the use case and the cost involved. "If you have a connected security camera, for example, you will probably take a staged approach," explains Miles Kirby, Managing Director at AV8 Ventures. "You will have some low power local compute in the camera which can process the incoming images and can wake up a more powerful edge processor for further analysis if there is something of interest happening. The local processing on the camera can determine, is that movement a cat, a tree blowing in the wind or a human being? If it looks like a human you could send the video clip to the edge compute, which will then analyse their intent. If they are wearing a mask and carrying a crowbar and heading towards an entrance, then you will upload the images to the cloud, re-verify the images with the full power of a data centre and alert the police if appropriate."

Wide area security and safety monitoring

With 5G networks in place, it will be straightforward to deploy connected HD cameras to monitor outdoor locations, such as international borders and coastlines, and along important infrastructure, such as train lines. Cameras could be mounted on solar-powered drones, which can achieve 14-day flight times, enabling constant "eye-in-the-sky detection" for key sites and at key times. All these cameras will be linked to intelligent control centres, where AI systems can analyse the activities, body language and facial expressions of suspects, enabling more automated monitoring with fewer trained staff. Moreover, key suspects can be digitally marked to assist with manual and auto surveillance, while security teams could wear connected clothing that will continually transmit their location and status and enable them to summon emergency assistance.

Connected cameras coordinate emergency management

In the 5G era, the emergency services will make extensive use of connected cameras to control and coordinate their operations. The police and fire brigade will wear body cameras, while drone-mounted cameras will conduct local area surveillance, and video cameras will be mounted on emergency service vehicles. This video footage, which will need to be very high quality, will be fed simultaneously into local sites and mobile control centres.

"Network slicing will allow operators to provide different propositions to different people, enabling them to give the emergency services, for example, priority," says Ameet Shah, former Group Strategy Director at BT. "That is what is happening with the emergency services – the blue light guys will be a test case for this concept. If you have got a terrorist incident and you need a live stream from the body cameras of the first responders, the telco will be able to give that priority over a teenager playing a video game."

IMMERSIVE EDUCATION AND TRAINING

Already popular with some gamers, virtual reality (VR) and augmented reality (AR) headsets could also be used for education and training. For example, trainee engineers, mechanics and even medics could learn how to perform specific tasks by following instructions relayed via AR or by using VR simulations. Similarly, these kinds of technologies could be used to teach biology and geography students about specific habitats and environments, either by superimposing digital information on images of the real world or by simulating the real world in virtual reality.

"In the 5G arena, it will become much easier to simulate something in real-time," says Arnie Sriskandarajah, Head of Venture Capital, Round Hill Capital. "Today, the quality of the imagery and the reactiveness is not ready to go mainstream. It is not about the quality of the code, it is about not being able to react in real time to the multitude of data inputs from third parties. We are waiting for the tipping point in connectivity that will give the early users a much better experience. With 4G today, there is too little bandwidth and too much latency for these sorts of tasks. 5G will allow mobile applications to react at fibre-optic speeds."

To date, the development of these kinds of interactive and immersive training applications has been limited by the high latency of most internet connections. 5G networks will remove these limitations, paving the way for a radical change in the way people approach education and training, which could take place almost anywhere and anytime.

In many cases, digital education and training courses will borrow techniques from video gaming to keep students engaged. Indeed, so-called serious games could be widely applied in fields, such as healthcare, engineering and the armed forces, where people need to learn hands-on skills. At the same time, highly reliable and responsive wireless connectivity will enable new forms of hands-on learning by enabling the haptic overlay of the learner and teacher. The teacher will be able to feel the learner's movements when they undertake a task involving fine motor skills, and correct as necessary. The learner will be able to see, hear and feel the exact movements their trainer has made, be they an engineer, pilot or surgeon.

WASTE NOT, WANT NOT

As the world's population climbs inexorably towards eight billion, the planet's resources – land, fresh water, fossil fuels and other minerals – are coming under increasing pressure. As policymakers, businesses and individuals seek to reduce waste, they are turning to connectivity to improve efficiency and better match supply and demand. For example, utilities in Toronto are using Mobile IoT connectivity to monitor the pressure in their water pipes to improve leak detection and preserve supply. The pressure data is relayed to a smart city platform, which analyses it to help identify any potential issues with the water supply. By enabling large numbers of sensors to be connected in each cell, 5G will accelerate the deployment of such solutions. It will enable people to have real-time information on everything from soil acidity to water pollution to the availability of parking spaces.

Smarter agriculture

With 5G, farmers will be able to boost yields and crop quality by precisely monitoring soil and weather conditions to tailor the use of pesticides and fertilisers. Connected vehicles could increase the efficiency of food distribution through optimal routing and monitoring of temperature control of food in transit. Better use of mobile refrigeration will lead to crops being delivered in better condition with longer market and shop lives.

Reducing environmental impact

By giving people fingertip control over their assets, 5G will help them to better manage their energy usage, reduce their greenhouse gas emissions and tap new, cleaner sources of power. With ubiquitous and reliable wireless connectivity, policymakers will be able to better incentivise citizens to select green options for transport, for running their home and for recycling of waste. For example, China Mobile is working with the municipality of Zhengzhou to employ Mobile IoT connectivity to manage the use of electric bikes in the city of about 10 million people. The plan is to monitor all three million electric bicycles in Zhengzhou using NB-IoT-connected positioning modules. The system will be able to collect information on the position, speed and temperature of each bike, allowing for proactive maintenance and greater safety.

SMARTER CITIES AND BUILDINGS

Mobile connectivity is already helping buildings and cities to become smarter, safer and more sustainable. The rollout of 5G will accelerate this trend by enabling the deployment of large numbers of connected sensors and actuators. That will give municipalities, organisations and individual citizens the ability to monitor what is happening in and around their properties and control access.

"We are looking at how to use big data to gauge the intensity of usage of different spaces, to enable smart city applications," says Arnie Sriskandarajah, Head of Venture Capital, Round Hill Capital. "With the broader bandwidth provided by 5G, you will be able to do much more expansive analytics and data crunching using real-time data feeds, such as those from social media and third parties. You can bring all of that together in the cloud."

He stresses this is very much a near-term opportunity, adding: "We see this coming together in Q2 and Q3 in 2020, depending on the delay in the technology reaching affordability. By then you could support real-time use cases where you are managing the movement of people around a space. We are looking at digital twins that employ multiple sources of data. We are looking at business models where you invest depending on how much a property is used."

Intelligent connectivity could also enable individual buildings to become much more flexible, adapting to the changing needs of their owners and occupants. "5G enables you to take the IoT from a data network to a control network," says Phil Skipper, Head of Business Development (IoT), Vodafone. "There is no reason to have complicated equipment in a building. You can move it into the cloud, which makes you much more agile – you have the ability to flex the building. You can rent it in much smaller slices, by the desk, rather than by the floor. And with the wireless office, you don't have an infrastructure problem. You have the ability to configure that building in a much more flexible way."

At the same time, intelligent connectivity can be used to remotely control access to a building without being reliant on physical keys or access cars that can go missing. "When someone leaves a company, you no longer have to get their access card back from them," says Phil Skipper. "You can send new biometrics or an access code down to the lock. Smart locks can transform key management – you'll no longer need a cupboard with millions of keys, which takes a lot of time to manage, as the keys get lost and the locks need to be changed."

The rollout of 5G will also help consumers to remotely control their properties using mobile operators' smart home platforms. For example, Orange plans to enable consumers to link appliances and devices in their homes to its Livebox wireless router and manage them remotely. Orange also intends to launch a security service, called Protected Home, in partnership with Groupama, which will see houses connected to a video surveillance centre that can contact a law enforcement agency if required.

CONCLUSIONS

Although the early uses cases for 5G will focus on better mobile broadband and fixed wireless services, this highly versatile mobile technology has the potential to trigger a major wave of innovation across the economy. By enabling a dramatic expansion in the Internet of Things and the data available for machine learning, 5G will deliver the intelligent connectivity required for many futuristic applications from self-driving cars and advanced robotics to virtual presence and the tactile Internet. Over time, it promises to make the death of distance[3] complete.

Many aspects of daily life, from the way we consume entertainment to the way in which we learn and interact with colleagues, will become much richer and more fulfilling. Individuals will always have the information and services they need at their fingertips, meaning both businesses and the public sector will become far more efficient and effective.

"3G enabled the rise of the connected consumer, 4G led to the digital consumer and 5G will drive the transition to the augmented consumer," says Pablo Iacopino of GSMA Intelligence. "But most 5G use cases will need ecosystem collaboration and customer adoption. Much work is needed to ensure that all these parties move together at the same speed."

At the same time, 5G and network slicing should enable mobile operators to provide their customers with rich, multi-faceted services. "Our customers want us to deliver much more than connectivity and we can do that better with 5G," says Carlos Carazo Cepedano, Global IoT Platforms & Technology Director at Telefónica. "Cellular connectivity will become the leading connectivity for the IoT."

Together, 5G, the IoT and AI will enable both start-ups and established companies to create compelling new services that will anticipate people's wants and needs, while helping them navigate life's challenges and setbacks. Indeed, 5G will act as a platform that will enable all kinds of players to roll out new products and services, says Ameet Shah, former Group Strategy Director at BT. "You will probably see a 10X increase in the number of connected devices, something of that order of magnitude. From an application perspective, that is profound and will change the world."

More broadly, intelligent connectivity is one of the key building blocks of a sustainable future. By capturing a wealth of real-time data, 5G will enable people to manage resources far better than has been possible in the past, while making transport both safer and more efficient. Scientists will use the data collected by 5G networks to create the smart systems and new technologies humanity will need to address some of its most pressing challenges, including climate change, an aging population and the spread of both chronic and infectious diseases.

[3] The concept of removing physical and geographical barriers to the diffusion of information and communications.