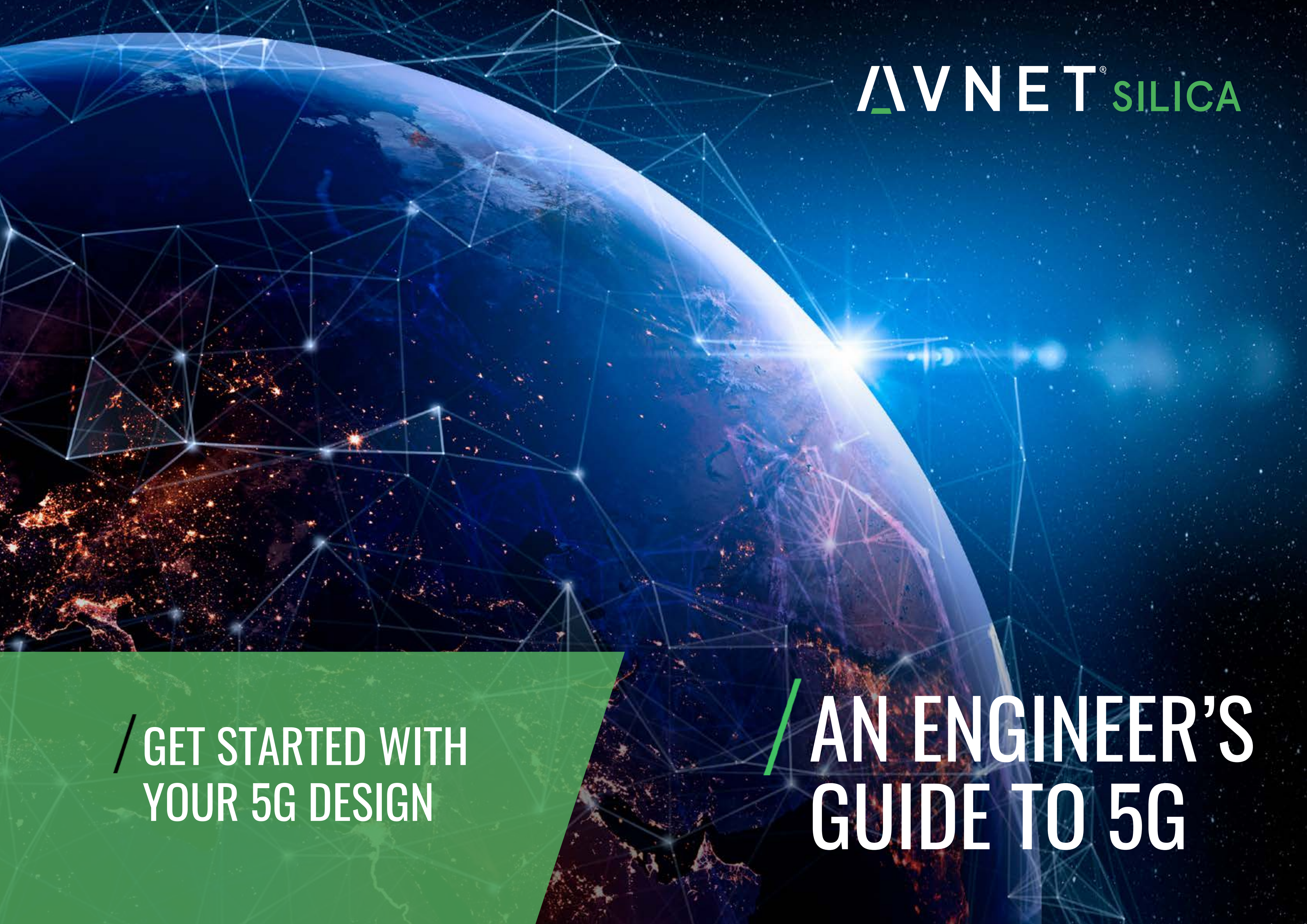

AVNET SILICA

AN ENGINEER'S GUIDE TO 5G

GET STARTED WITH YOUR 5G DESIGN

INTRODUCTION

The 5G global roll-out has now entered its 4th year and this revolutionary networking technology is increasingly underpinning the capabilities of an expanding range of devices and applications across multiple sectors.

The high expectations on 5G are predicated on its ability to deliver fibre-levels of speed, capacity, and latency, removing historical restrictions on applications as diverse as autonomous automobiles, remote telesurgery and automated factory production lines.

This guide provides a comprehensive overview of 5G, with information on its origins, capabilities, and applications. It covers the key standards and technologies behind this latest mobile networking generation, and its transformational power is illustrated through references to typical use cases and current applications.

Starting with an overview of the various generations of cellular technology, the pressures on existing 4G/LTE networks are described, highlighting the drivers behind 5G's development. Reference is made to the 3GPP standards process which governs the ongoing evolution of 5G and the reader is pointed to valuable sources of information on these standards.

Section 2 of the guide offers a glimpse of a 5G-enabled future, showing how its core capabilities of Enhanced Mobile Broadband, (eMB), Massive Machine Type Communications, (MMTC), and Ultra-reliable and Low Latency Communications, (URRLC), support a wide range of use cases. This mapping of capabilities to use cases is further illustrated through a selection of real-world examples.

Several key technological innovations are critical to the enhanced performance of 5G and an overview of these technologies is given in the later sections of this report, enabling the reader to understand how 5G is delivered and to gain insight into the challenges of designing 5G-ready equipment.

The outbreak of the global pandemic in early 2020 initially threatened the 5G deployment, and many analysts feared that the roll-out – and consequent economic value - would be compromised. Section three describes how these fears were short-lived as Covid-driven changes in work practices actually re-enforced the demand for 5G's enhanced network capabilities.

5G was launched amid significant expectations over its ability to transform society and support the delivery of substantial, incremental economic growth. This growth is dependent upon the ability of developers across all industrial and business sectors to innovate using 5G. The Avnet Silica Engineers' Guide to 5G provides engineers, developers, and managers with a valuable reference point for this vital, emerging networking technology.

INTRODUCTION

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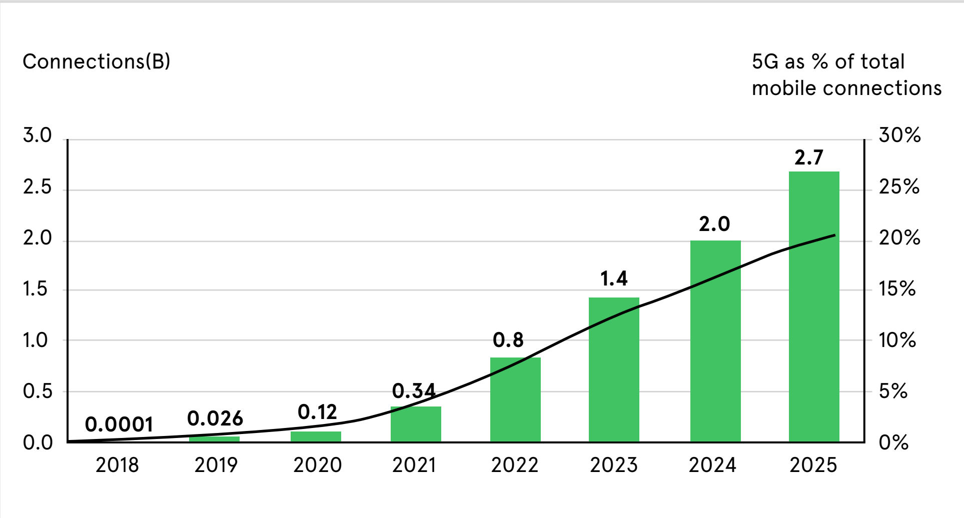
/ THE ROAD TO 5G

THE ROAD TO 5G

It's just over a year since the first 5G services were launched, in October 2018, by Verizon and AT&T in the USA and, since then, 5G networks have been rolled out in a further 17 countries with South Korea, the United Kingdom, Germany, and the United States leading the charge and China catching up fast.

With analysts forecasting 2.7 billion 5G connections by 2025, (Figure 1), the uptake of 5G is expected to be faster than any previous cellular generation and expectations are running high for its future impact on the global economy.

Forecast growth in global 5G connections



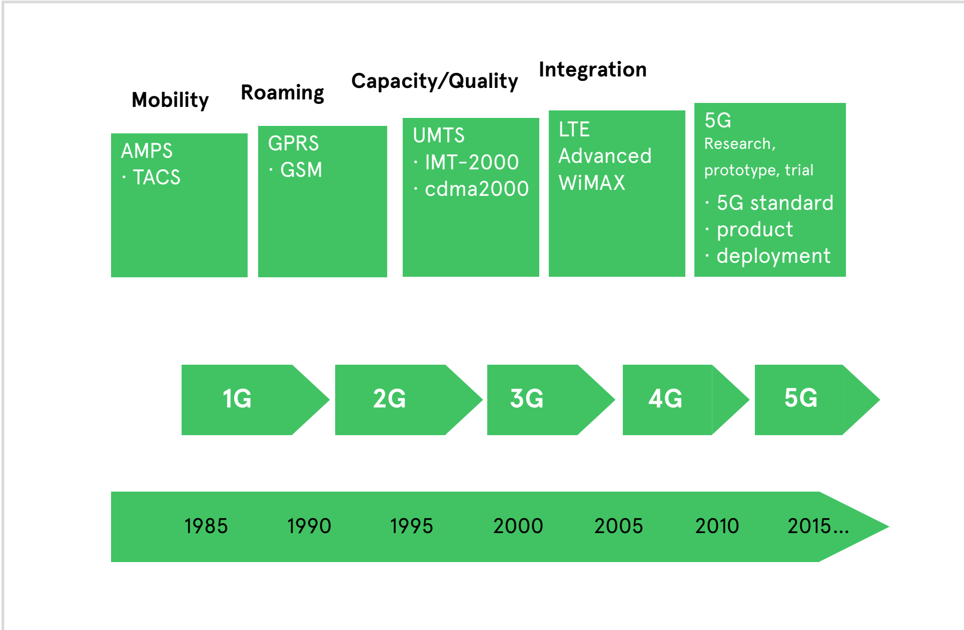
(Source: CCS Insight)

In this review of the evolution of cellular networking, we take a brief look at previous generations of networks before examining why 5G is different and how it is expected to deliver the many-anticipated economic benefits.

A Trip Through the Generations

Since their initial arrival in the late 1970s, cellular networks and technology have evolved considerably, with successive generations, (2G through 4G) representing significant milestones in the development of mobile connectivity (Figure 2).

Cellular network evolution timeline



(Source: https://www.researchgate.net/figure/Mobile-Cellular-Network-Evolution-Timeline_fig1_263657708)

THE ROAD TO 5G

First Generation
Although not called 1G at the time, first generation mobile networks emerged in Japan in 1979, before rolling out to other countries such as the USA (1980), and the UK, (1985). Based on an analogue technology known as Advanced Mobile Phone System (AMPS), which used frequency division multiple access (FDMA) modulation, 1G networks offered a channel capacity of 30 KHz and a speed of 2.4 kbps.1G networks only allowed voice calls to be made, suffered from reliability and signal interference issues and had limited protection against hackers.

Second Generation (2G)
Despite its flaws the 1G network wasn't superseded until 1991, when 2G networks, were introduced. Based on digital signalling technology, GSM, which increased security and capacity, 2G networks offered bandwidths of 30 to 200 KHz and allowed users to send SMS and MMS messages, although at low speeds, up to 64kbps. Continuous improvement of GSM technology led to the introduction of so-called 2.5G, which incorporated packet switching in the form of GPRS and also EDGE technology. 2.5G enabled data-rates up to 144 kbps, enabling users to send and receive e-mail messages and browse the web.

Third Generation (3G)
The arrival in the year 2000 of 3G, known as UMTS in Europe and CDMA2000 in the USA, heralded a change in the way mobile phones were used and viewed by the end user, becoming less about voice calls, more about social connectivity. Also based on GSM, the main aim of 3G was to support high-speed data and the original 3G technology allowed data-rates up to 14 Mbps. With its ability to transmit greater amounts of data at higher speeds, 3G enabled users to make video calls, surf the web, share files, play online games and even watch TV online. Whereas 2G networks would enable a 3-minute MP3 song to be downloaded in around 6-9 minutes, the same file would take anywhere between 11 and 90 seconds to download on a 3G network. Today the most common use for 3G networks is as a backup for 4G.

Fourth Generation (4G)
The introduction of 4G really ushered in the era of the smartphone and hand-held mobile device. 4G is the first generation to use LTE technology to deliver theoretical download speeds of between 10 Mbps and 1 Gbps, offering end users better latency (less buffering), improved voice quality, instant messaging services and social media, quality streaming and faster download speeds. 4G is also the first IP-based mobile network, handling voice as just another service and the technology is being developed to accommodate the QoS and rate requirements required by applications including wireless broadband access, Multimedia Messaging Service (MMS), video chat, mobile TV, HDTV content, Digital Video Broadcasting (DVB).

In the relatively short time since their introduction however, 4G networks are already struggling to cope with the demands placed upon them. Driven by emerging technologies such as augmented reality, (AR), autonomous vehicles and the exponential growth of the Internet of Things, (IoT), global demand for mobile bandwidth is growing at an explosive rate. Technology giant Ericsson predicts a compound annual growth rate (CAGR) of 39 percent in global mobile data traffic between now and 2023, equating to a total of 107 exabytes (EB) per month. As well as being bandwidth hungry, emerging applications need higher speeds and lower latencies and the growing number of IoT devices is fuelling demand for ever higher numbers of connections – to over 29 billion by 2022, according to Ericsson.

Realising that 4G/LTE networks will ultimately reach capacity, the International Telecommunications Union, (ITU), in 2015, defined the requirements specification for 5G.

THE ROAD TO 5G

5G: Revolution not Evolution

The ITU specification for 5G, contained in the document, ITU-R IMT-2020 (5G), is summarised in Figure 2. The ambitious specification represents a step-change in performance over 4G and aims to address the requirements of the emerging applications, described above. Throughputs up to 10 Gbps (100 times faster than 4G networks) aim to satisfy the growing hunger for bandwidth; latencies of 1 mSec (c.f. 30 – 50 mSec for 4G) will enable near-real-time response rates; and connection densities of 1000 devices per square kilometre (100 times more than 4G) will support the growing numbers of IoT devices and sensors.

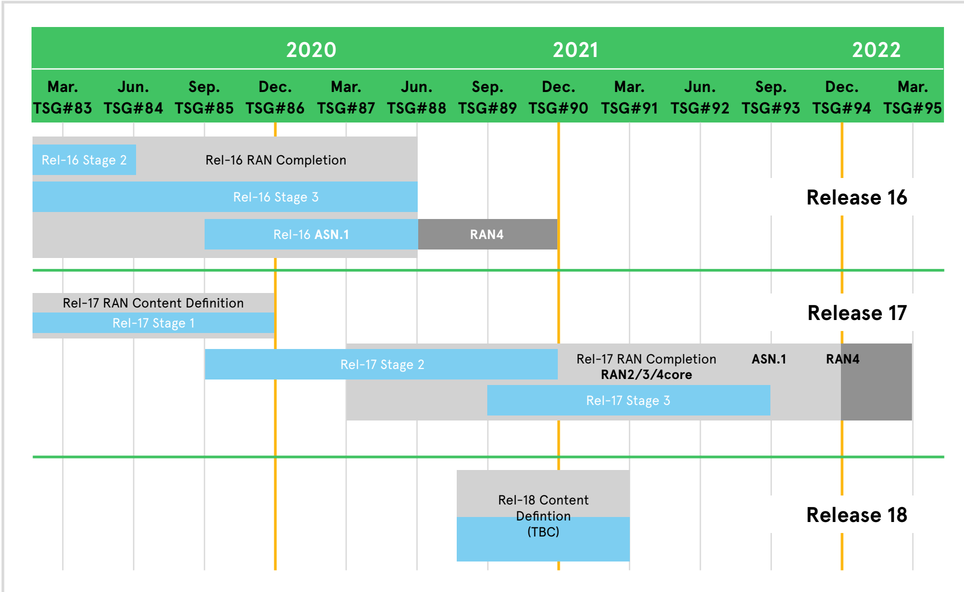
Selected key performance indicators of 5G according to ITU-R

Peak data rate	**10Gb/s** (uplink) **20Gb/s** (downlink)	**Connection density**	1 thousand - 1 million devices / km^2	**Reliability**	99.999 % (of packets)
User experienced data rate	10-100Mb/s	**Battery life**	10 years	**Position accuracy**	<1 m - 10 m
Latency	1-10 ms	**Availability**	99.999 % (of time)	**Security**	Strong privacy & security, and purification

(Source: "5G for Connected Industries and Automation", 2nd edition, White Paper, 5GACIA, November 2018)

Having completed the 5G specification, the ITU delegated the definition of the 5G technical specifications to the global standards body, 3GPP. Founded in 1998, 3GPP is a global cooperation of independent standardisation committees (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), and has been responsible for the definition of technical specifications for wireless standards since the introduction of 3G. 3GPP prioritises and groups specifications into releases, based on the sequence in which new functionality will be deployed in wireless networks. 5G specifications have been integrated into 3GPP releases 15 and 16, Figure 3, with release 16 scheduled for completion in time for the ITU's 2020 deadline. Completion of these specifications ensures that operators and manufacturers of 5G technology can have confidence in their designs and investments.

3GPP release 15 and 16 schedule

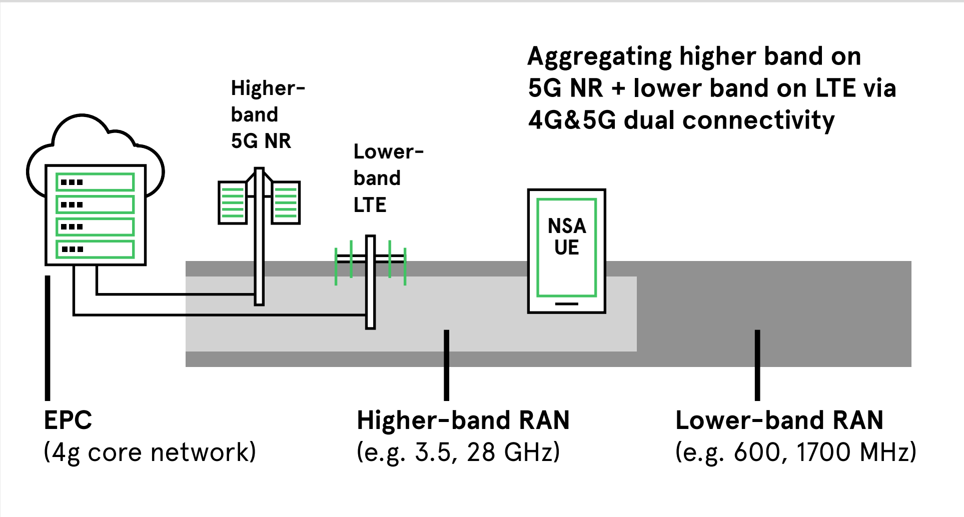


(Source: 3GPP)

THE ROAD TO 5G

Full deployment of all of the 5G capabilities defined in IMT-2020G requires implementation of totally new networks, significant investments by operators and considerable elapsed time to enable a full roll-out. To ease the migration path and enable operators to get to market early with 5G services, 3GPP defined 5G NR non-stand alone, (NSA) technology in release 15, Figure 4.

5G NR non stand-alone



(Source: Qualcomm)

5G NSA enables 5G services to be provided by leveraging existing LTE infrastructure. The throughput of existing macro cells can be increased by adding extra MIMO layers and operators can use existing spectrum in the so-called "MIMO sweet spot", around 3.5 GHz to offer a mainly consumer proposition, providing faster services to new 5G handsets.

Release 15 also includes the specifications for 5G NR stand-alone (SA) technology and release 16, scheduled for completion in early 2020, addresses the specifications for mmWave technology, based on spectrum allocation decisions due to be taken following the ITU's World Radio Conference in October of 2019.

A review of 5G launch announcements, Table 1, confirms that the NSA route is popular with many operators around the world, with key exceptions being AT&T and Verizon who are using their mmWave licences to provide fixed wireless access (FWA) services to consumers.

Summary of global 5G launch plans

Operator	Frequencies	Services
AT&T	39 GHz	Home Broadband
Verizon	28/39 GHz	Home Broadband
T-Mobile (USA)	600 MHz	Consumer, handsets, tablets, etc.
EE	3.4 GHz	Consumer, handsets, tablets, etc.
Vodafone	3.4 GHz	Consumer, handsets, tablets, etc.
China Unicom	3.5 – 3.6 GHz	Consumer, handsets, tablets, etc.
South Korea (all 3 operators)	3.5 GHz	Consumer, handsets, tablets, etc.

THE ROAD TO 5G

5G is Poised to Change the Way We Live

It is only around 40 years since the birth of mobile telephony and in that time the capabilities of cellular networks have evolved at a pace which has fuelled both social change and innovation on a global scale. The capabilities of 3G then 4G networks were developed in response to demands for a mobile internet and have led to the smart-phone and tablet becoming everyday accessories. However, the inexorable rise of the IoT and the demands of emerging applications such as AR/AI and self-driving cars have stretched the capabilities of 4G networks to their limits leading to the development of the next generation of cellular networking, 5G.

Whereas 3G and 4G networking were focused on voice and data services and are mainly associated with the smartphone, 5G offers much more, promising to enable the inter-connection of billions of devices of almost any kind. More than a faster wireless capability, 5G promises to transform existing consumer, business and industrial processes, unlocking new levels of productivity and innovation and driving the next wave of global economic growth. The 5G roll-out has only just begun but, with operators poised to invest in the infrastructure required to unlock the full power of 5G, the global economy stands on the verge of the next wave of growth.

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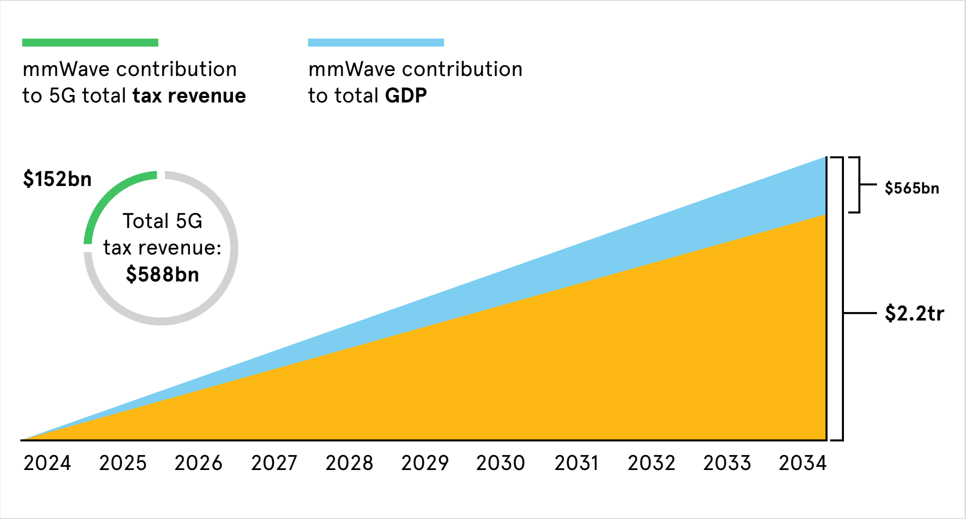
/ THE FUTURE IS 5G

THE FUTURE IS 5G

Whilst we are still early in its deployment cycle, 5G's characteristics and performance capabilities are well defined and its potential to enable new and improved applications is already clear. Beyond those applications which have already emerged, however, it is widely anticipated that 5G will transform many areas of our life by enabling further levels of innovation across multiple vertical segments, including healthcare, automotive, smart cities and industrial automation.

Most analysts and industry commentators are united in their view that 5G will underpin the next wave of growth in global GDP and a recent report, commissioned by the GSMA, a trade association representing the interests of global mobile network operators, concluded that 5G will contribute $2.2 trillion to the global economy over the next 15 years (Figure 1), with the biggest beneficiaries being the manufacturing, utilities, and professional and financial services sectors.

Estimated impact of 5G on the global economy



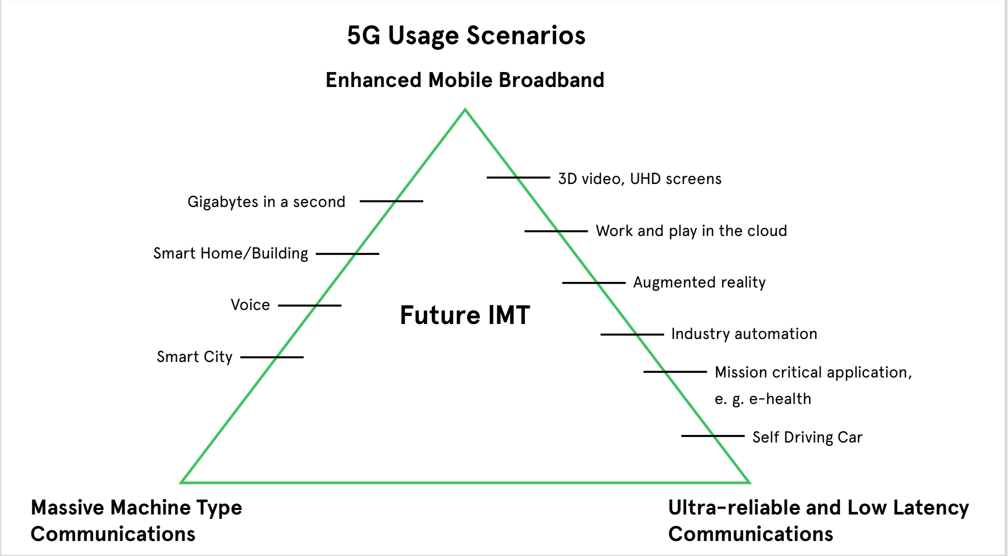
(Source: GSMA)

This article explores how 5G's enhanced network performance is enabling innovative applications in diverse fields such as autonomous vehicles, remote surgical robots and massive IoT sensor networks. These solutions are early examples of 5G's transformative capabilities and provide engineers with a vivid illustration on how to capitalise on 5G's potential.

5G Enables a Powerful Set of Use-Case Scenarios

5G's network capabilities were specified to address the requirements of three broad use-case scenarios, as illustrated in the diagram published by the ITU (Figure 2) and summarised below.

3 Broad 5G use cases



(Source: ITU)

PREVIOUS NEXT

Enhanced Mobile Broadband, (eMBB)
With extremely high data-rates, up to 20 Gb/s, eMBB provides an improved consumer experience and also supports high bandwidth applications such as augmented reality (AR), artificial intelligence, (AI) and virtual reality, (VR)

Massive Machine Type Communications (mMTC)
mMTC provides wide-area coverage and deep indoor penetration for an extremely large number – up to 1 million per square kilometre - of connected devices. This use-case addresses the requirements of the rapidly growing mobile IoT, by providing Low-Power-Wide-Area, (LPWA) technologies which enable low power consumption, improved coverage and optimised transmission for small and intermittent blocks of data.

Ultra-Reliable and Low Latency Communications (URLLC)
URLLC supports highly mission-critical applications which are heavily dependent on extremely low end-to-end (E2E) latencies (one millisecond or less), along with high reliability and availability.

In practice, not all applications will require to use all of 5G's capabilities whilst others may require different combinations, as illustrated in Figure 2, often varying dynamically. A remote IoT sensor, for example, will have a consistent need for low battery usage and low power, low data rate communications, placing it firmly in the mMTC use case. Remote robotic surgery will, as we will see later, require a combination of eMBB and URRL capabilities, as the application must transfer large quantities of sensor data from the robotic device to the surgeon whilst also enabling near real-time responses during the operation.

This changing mix of requirements is handled by 5G's network slicing functionality which enables the allocated network resources to change dynamically, in-line with the application's needs.

Emerging Applications Give Insight into the Power of 5G

As discussed earlier, there are significant expectations on the contribution that 5G will make to future global economic prosperity. Although much of this contribution will come from applications which are yet to emerge, 5G's potential benefit areas can be classified as described in Table 1 and the remainder of this section considers a sample of current, high profile applications which are already integrating 5G capabilities.

Summary of anticipated 5G benefits

Benefit Area	Examples	Services
Improved connectivity	Faster and more reliable connectivity for a wide range of users in environments such as road and rail, dense areas and at home	Increased consumer value and productivity gains
New consumer devices and services	Smart devices and services including immersive media and entertainment, healthcare wearables, and autonomous vehicles	Variety of consumer and business benefits, driven by innovation
New IoT solutions	Examples include advanced asset tracking, remote control, predictive maintenance and sensor-enabled processes across multiple sectors	Increased productivity
Smarter infrastructure and public services	Street lighting, traffic management, energy grids	More efficient and secure service delivery, environmental benefits

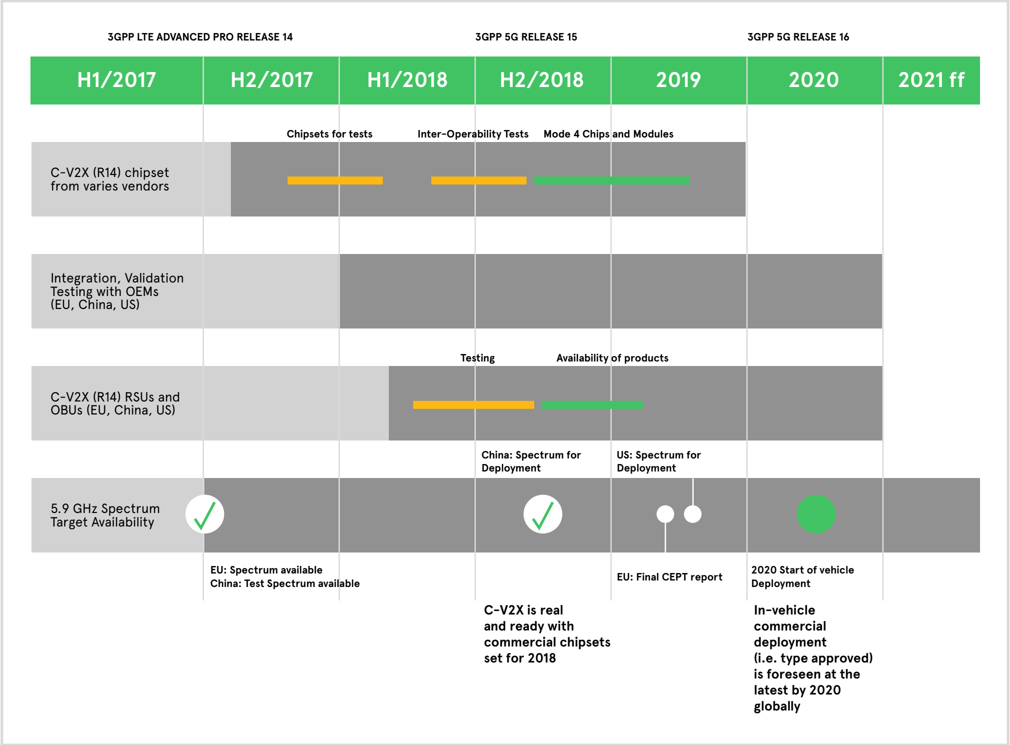
THE FUTURE IS 5G

Autonomous Vehicles
The driverless car is a leading example of a current, high-profile technological development, with vehicles such as Google's Waymo, BMW's Vision iNext and Tesla's models frequently featuring in headlines. Although these vehicles are still very much at the development stage, analysts are predicting strong growth in this sector over the next five years, with widespread availability of 5G networks being seen as a fundamental pre-requisite to this growth.

Reliable and safe operation requires that the autonomous vehicle must continuously interact with its environment, communicating with other vehicles, roadside infrastructure, pedestrians, and other entities, such as remote data centres. This interaction will draw heavily on 5G's capabilities: URLCC enables the vehicle to respond and react in real-time; eMBB supports the transfer of large amounts of data – as much as 2 million Gbps - as the vehicle senses and communicates with its environment; and mMTC enables an extensive network of roadside sensors.

The subset of cellular technologies required to support autonomous vehicles has been termed vehicle to everything (V2X) and 3GPP has been building progressive cellular support for V2X into its releases

Timeline for deployment of C-V2X (V2V/V2I)



(Source: 5GAA, Timeline for Deployment of c-V2X – Update)

Remote Robotic Surgery

Another application capitalising on early 5G deployments is remote robotic surgery. Haptic, as well as visual, feedback is critical in surgery and the surgeon must react to both types of stimuli in under 10 mSecs – a response time which has previously presented a barrier to remote surgery. Because of this, robotic surgical devices have until now had to be directly controlled by a surgeon within the same physical environment as the patient.

Now, however, a collaboration between telecommunications giant Ericsson and King's College London (KCL) is working on the application of 5G technology to remote telesurgery. Ericsson has developed specialised haptic gloves, enabling a surgeon to operate on a patient using a robotic device, with no loss of sense of touch. The eMBB capabilities of 5G are used to stream the haptic data from the advanced sensor arrays on the robotic device, along with video from the operating theatre. The URLCC capabilities of 5G are crucial in enabling the data to be streamed from the remote operating theatre to the surgeon within the required 10 mSec delay.

5G networks have already enabled real world operations using remote tele-surgery when, in March 2019, People's Liberation Army General Hospital (PLAGH) chief physician Ling Zhipei performed brain surgery on a Parkinson's disease patient in Beijing from the PLAGH Hainan Hospital 3,000km away.

The IoT

The explosive growth of the IoT shows no signs of abating, with Gartner forecasting 20.8 billion connected "things" by 2020, and IHS Markit predicting that this number will rise to 125 billion by 2030. IoT applications span most sectors, including the Industry 4.0 factory, smart cities, agricultural monitoring, pipeline monitoring, aircraft maintenance and many more, with the intelligent sensor or "thing" as the common denominator.

A significant proportion of these applications require LPWAN technologies which are characterized by enhanced indoor, outdoor and underground coverage and enable battery-powered devices, which transmit data only occasionally, to achieve battery lives of up to 10 years. Many operators have been developing LPWAN offerings based on either NB-IoT or LTE-M networks, both of which were defined in 3GPP Release 13, with the GSMA reporting 89 NB-IoT networks and 34 LTE-M launches as of October 2019.

Recognising this investment, 3GPP has confirmed that both technologies meet the 5G specifications and will underpin the mMTC capability as the 5G standard continues to evolve, guaranteeing a smooth migration path for existing solutions.

THE FUTURE IS 5G

The 5G Journey is Just Beginning

The roll-out of 5G is just over one year old but, even before the first network was deployed, expectations of 5G were exceptionally high, with analysts predicting that it will be the next driver of global economic growth, enabling significant future value creation across multiple sectors.

5G's real value will be based upon enablement of emerging applications rather than on faster handsets, and this article has considered how 5G's capabilities are enabling a sample of these current applications. We are clearly only at the beginning of a long road with 5G, but the pace of innovation can only be expected to accelerate as operators embrace the full opportunities offered by investing in fully functional 5G networks.

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/ XILINX INNOVATIONS WINNING THE 5G RACE

Wherever 5G drives innovation, from over the air, satellite to ground, and private network to 4.0 automation, cutting edge 5G applications require both increased bandwidth, and fast computing into a lower power and smaller form factor radio.

The RFSoC product family's breakthrough integration translates to lower power, a smaller footprint, and higher performances. It enables demanding 5G applications such as multi operators, 400MHz iBW, Multi Carriers, Sub 6GH and MMwave, whilst supporting ease of use and flexibility of design evolution.

By enabling a 'Radio in One chip' design (from O-RAN interfaces to RF) with high performance and low power, the Zynq RFSOC family provides significant benefits for applications that require fast computing at a lower cost.

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5G ENABLES THE GLOBAL ECONOMY TO SURVIVE THE PANDEMIC

5G ENABLES THE GLOBAL ECONOMY TO SURVIVE THE PANDEMIC

When the COVID-19 pandemic struck in the early months of 2020, surveys predicted that the 5G roll-out would be severely impacted by investment slowdowns, severe economic downturns, plummeting consumer confidence and supply chain disruptions. In reality, although there were indeed a number of short-term impacts, the global healthcare crisis actually emphasised the importance of digital infrastructure. Businesses around the world have rapidly adapted to the constraints imposed by COVID-19, implementing virtual modes of operation, and citizens have found new ways of interacting and engaging socially.

COVID-19 has actually underscored the economic and environmental importance of 5G, a critical enabler of digital infrastructure. By the end of 2020, the industry was optimistic about an eventual, full recovery for 5G, with IHS Markit, a London-based analyst, revising their 2019 investment forecast upwards. The new forecast predicts a 10.8% net increase in 5G investments for the period 2020-35, compared with the pre-COVID view, reflecting the value in a post-pandemic world of the emerging 5G use cases.

5G Helping the World adapt to COVID-19
In the period since its emergence, COVID-19 has had a devastating impact on the world, with the World Health Organisation, (WHO), reporting 271,963,258 worldwide cases as of 17 December 2021 and 5,331,019 deaths. Although vaccines have emerged during 2021 to slow the spread of the disease and reduce its impact, there have been multiple twists and turns along the road, with successive waves still impacting many countries.

During this time, almost every aspect of human activity, including work, leisure, health, education, and retail have been profoundly impacted by the virus.
These social and economic disruptions have had a significant impact on the global dependence on digital communications and, in particular, the rollout of 5G.

In 2020, consumer use of fixed broadband connectivity increased, on average, by two and a half hours per day and of mobile by one hour. In its recent 5G Outlook Series report , the World Economic Forum highlighted a range of activities driving this increased usage, including a 490% increase in telemedicine consultations, a 75% increase in online gaming and a 74% increase in online retail transactions.

In their June 2020 Mobility Report, Ericsson, a Swedish multinational networking and telecommunications company reported that 60% of white-collar workers increased their use of video calls.

5G ENABLES THE GLOBAL ECONOMY TO SURVIVE THE PANDEMIC

The Global Pandemic is Shaping Five Connectivity Trends

COVID-19 has highlighted the growing importance of connectivity for the global economy and environment, with five key trends emerging.

A massive, global shift to remote working
With social distancing measures placing severe restrictions on use of office space, millions of workers have been unable to access their normal workplaces during the pandemic and a 2020 survey by Global Workplace Analytics, a research-based consulting firm, showed that as much as 88% of the global workforce were working from home during 2020 – up from 31% pre-pandemic. This trend is reflected in an increased dependency on connectivity, with AT&T, in the USA reporting a 22% increase in core network traffic and, in Asia, Korea Telecom reporting a tripling of traffic since the launch of 5G, driven mainly by video traffic.

Replacement of classroom learning with remote schooling
COVID-19 has had a profound impact on pupils, teachers, and schools, with estimates of 1.2 billion children in 186 countries being shut out of the classroom during the lockdowns of 2020. Education has therefore had to adapt dramatically, resulting in the rise of e-learning, with teaching delivered remotely, using digital platforms. Whilst research indicates that online learning increase retention of information and takes less time, there is a risk of an education gap appearing, across countries and between income brackets, based on access to digital technology. Government education policies need to address this growing issue to ensure that the pandemic does not leave a legacy of a digital divide. Early signs are encouraging, with schools globally allocating 15.9% of budget to Educational Technology in 2020, up from 3.9% in 2018.

Substitution of in-person gatherings for online socialisation
The physical distancing measures introduced by many governments have fundamentally impacted our daily lives, in some cases, threatening our mental health and wellbeing. With more and more people working from home, the internet increasingly offers a means of staying connected to friends, social lives and everyday hobbies and activities. Social media use has accelerated through the pandemic and innovative ways of socialising are emerging, such as group video chats, online dinner parties, quizzes, book club meetings, virtual exercise classes and online gaming, where traffic is up by 75% compared with pre-COVID levels.

Shifts in commerce and retail in response to sudden changes in consumer behaviour
COVID-19 imposed physical restrictions have impacted heavily on the retail sector, with shopping habits dramatically accelerating the shift from traditional stores and shopping malls to online and e-commerce channels. Kantar, a media research company, predicts that e-commerce will account for two-thirds of retail sales growth over the period 2020 -25 with online outlets such as Amazon, Wayfair and Etsy benefiting at the expense of traditional establishments. Although existing mobile broadband services can adequately support many aspects of e-commerce, 5G's enhanced capabilities promises to further enhance the consumer experience and bring productivity gains to the on-line retailer.

The global public-health crisis response
Even before the pandemic, healthcare was one of the largest industries, with spending ranging between 10% and 14% across developed countries. Wireless communication technology was already well embedded in healthcare, but COVID-19 is providing both the opportunity and the imperative for further developments. Physical distancing requirements have placed severe limitations on both hospital and doctors' surgery visits, driving significant growth in tele-medicine, where telephone or video consultations have replaced in-person visits. In a March 2020 report, Forrester research were forecasting that virtual healthcare interactions would exceed one billion by the end of the year and Frost and Sullivan estimated that tele-health visits with doctors grew by 50% during the month of March 2020.

5G ENABLES THE GLOBAL ECONOMY TO SURVIVE THE PANDEMIC

The Pandemic and 5G

The above trends driven by the global pandemic have highlighted the growing global dependence on mobile technology and accelerated the development of a multitude of use cases. While it is true that many of these use cases can currently be supported by existing 4G/LTE networks, their rapid growth is emphasising the need for 5G's advanced capabilities.

The global demand for bandwidth was already putting current generation networks under pressure and was a key driver of 5G development. COVID-19 has further accelerated this demand and the availability of 5G, with its increased and more efficient use of spectrum, is more crucial than ever.

Figure 1 illustrates how 5G's functional capabilities are enabling a wide range of use cases, including those discussed above. Enhanced mobile broadband and low latency communications support a wide range of applications which are both bandwidth hungry and time sensitive, spanning tele-health, industrial and educational use cases. Massive Machine Type Communications will support the explosive growth in connected devices upon which these use cases will depend and, increasingly, low power-networking techniques will contribute to the development of sustainable applications.

The pandemic is accelerating the need for 5G's capabilities

Functional driver	Description	Added value	Use cases
Enhanced mobile broadband (eMBB)	Faster connections, higher throughput and greater capacity (up to 10 Gbps)	Allows for an extension in cellular coverage into diverse structures (large venues) and the ability to handle a larger number of devices using high amounts of data	Fixed wireless access service, enhanced in-building broadband service, real-time augmented reality service, real-time virtual and mixed reality service, crowded or dense area service, enhanced digital signage, high-definition cloud gaming, public protection and disaster response services, massive content streaming services, remote surgery and examination
Ultra-reliable low latency communication (uRLLC)	Reduced time for data from device to be uploaded and reach its target (1ms compared to 50ms for 4G)	Enables time-sensitive connections wirelessly	Autonomous vehicles, drones and robotic applications, health monitoring systems/telehealth, smart grid and metering, intelligent transportation, factory automation, remote operation, self-driving cars, mission-critical services (security and safety), high-definition real-time gaming
Security	Robust security properties, leading to high reliability and availability	Creates an ultra-reliable connection to support applications where failure is not an option	
Massive machine-type communications (mMTC)	Increased spectral efficiency plus small cell deployment	Allows for a large number of connections to support data-intensive applications	Asset tracking and predictive maintenance, smart cities/buildings/agriculture, internet of energy/utility management, industrial automation, smart logistics (advanced telematics), smart grid and metering, smart consumer wearables, environmental management, intelligent surveillance and video analytics, smart retail
Power efficiency	Efficient power requirements for massive multiple-input, multiple-output (MIMO), small cell implementation	Leads to lower costs and enables massive internet of things	

(Source: World Economic Forum: 5G Outlook Series

5G ENABLES THE GLOBAL ECONOMY TO SURVIVE THE PANDEMIC

The Pandemic has Strengthened the Case for 5G

Despite initial fears for the 5G roll-out, the trends that have emerged during the global pandemic have strengthened the case for investing in digital infrastructure, and 5G in particular. Emerging use cases have illustrated the economic benefits of this new technology, estimated before the pandemic at up to $2.2 trillion in the 15-year period to 2035.

It is generally recognised that the world will not return to its pre-COVID state; home working is here to stay for a substantial proportion of the workforce and advances in areas such as telemedicine and industrial automation will continue to support flexible working practices, enabling industry to function in an ongoing, uncertain environment.

Moving forward, governments and regulators must continue to support the roll-out of 5G to ensure that the world eventually emerges from the pandemic in a stronger position. The trends that have emerged during this global health crisis have underscored the importance of the digital evolution, enabled by 5G, in tackling current and future challenges, including climate change.

Get started with your design
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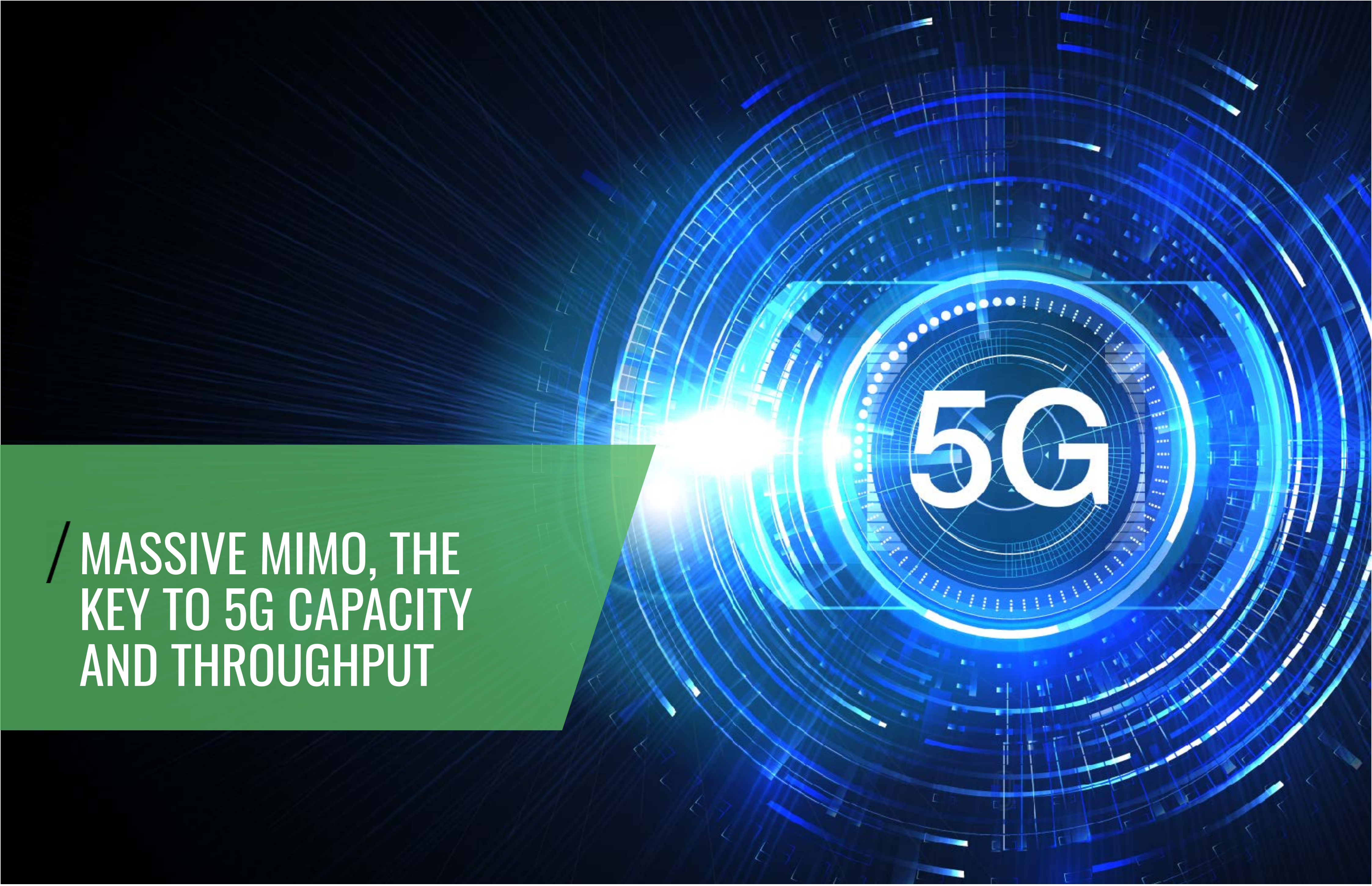


MASSIVE MIMO, THE KEY TO 5G CAPACITY AND THROUGHPUT

MASSIVE MIMO, THE KEY TO 5G CAPACITY AND THROUGHPUT

To meet the demanding requirements laid down in the International Telecommunication Union's specification for 5G, engineers had to adopt a fundamentally different approach to wireless network design. The transformational increase in performance of 5G New Radio, (NR), is based on a number of key technologies, including Massive MIMO and Beamforming, as well as on the use of OFDM, a highly spectral-efficient modulation technique and mmWave spectrum.

As the first in a series of articles examining these key 5G building blocks, we take a closer look at Massive MIMO, a key enabler and foundational component of 5G, and its role in increasing data throughput and capacity.

What is Massive MIMO?

MIMO, (multiple-input, multiple-output) is a radio antenna technology which deploys multiple antennae at both transmitter and receiver to increase the quality, throughput, and capacity of the radio link. MIMO uses techniques known as spatial diversity and spatial multiplexing to transmit independent and separately encoded data signals, known as "streams", reusing the same time and frequency resource.

In multi-user MIMO (MU-MIMO), the transmitter simultaneously sends different streams to different users using the same time and frequency resource, thereby increasing the network capacity. Spectral efficiency and capacity can be improved by adding additional antennae to support more streams, up to the point where power sharing and interference between users result in diminishing gains and, eventually, losses.

MIMO is used in many modern wireless and RF technologies, including Wi-Fi and Long-Term Evolution, (LTE). 3GPP, the global organisation responsible for the definition of wireless standards, first specified MIMO for LTE in 2008, in its Release 8. This initial variant used two transmitters and two receivers, 2x2 MIMO, and subsequent increases in processing power have enabled the use of more simultaneous data streams in operational wireless networks with current 4G LTE networks using 4×4 MIMO.

The very short wavelengths at mmWave frequencies translate to correspondingly smaller antenna dimensions and, for 5G NR, 3GPP has specified 32 antenna, (32 x 32 MIMO) in Release 15, rising to 64 and more in future releases. This expansion in the size of MIMO antenna has led to the term Massive MIMO.

MASSIVE MIMO, THE KEY TO 5G CAPACITY AND THROUGHPUT

Massive MIMO Techniques

Massive MIMO is based upon the three key concepts of spatial diversity, spatial multiplexing, and beamforming. MIMO builds on the fact that a radio signal between transmitter and receiver is filtered by its environment, with reflections from buildings and other obstacles resulting in multiple signal paths (Figure 1). The various reflected signals will arrive at the receiving antenna with differing time delays, levels of attenuation and direction of travel. When multiple receive antennae are deployed, each antenna receives a slightly different version of the signal, which can be combined mathematically to improve the quality of the transmitted signal. This technique is known as spatial diversity since the receiver antennas are spatially separated from each other. Spatial diversity is also achieved by transmitting the radio signal over multiple antennae, with each antenna, in some cases, sending modified versions of the signal.

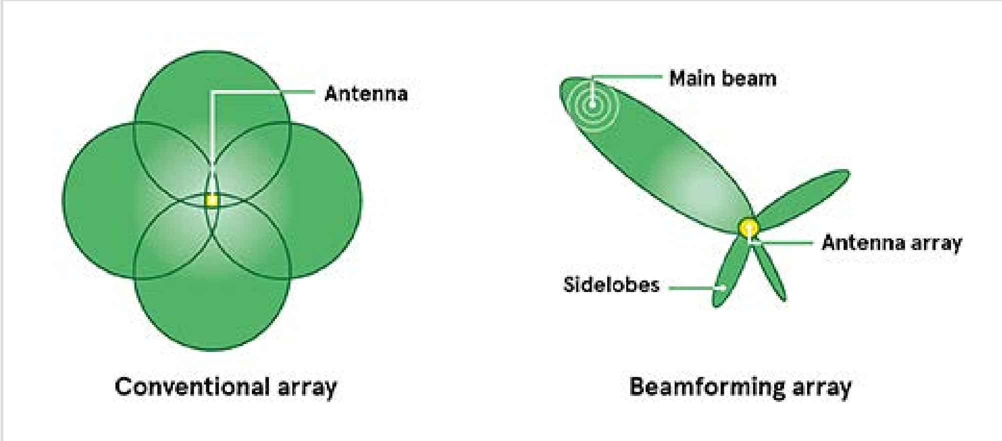
A radio signal can take multiple paths between transmitter and receiver

(Source: Qualcomm)

Whilst spatial diversity increases the reliability of the radio link, spatial multiplexing increases the capacity of the radio link by using the multiple transition paths as additional channels for carrying data. Spatial multiplexing allows multiple, unique, streams of data to be sent between the transmitter and receiver, significantly increasing throughput and also enabling multiple network users to be supported by a single transmitter, hence the term MU-MIMO.

Beamforming uses advanced antenna technologies to focus a wireless signal in a specific direction, rather than broadcasting to a wide area (Figure 2).

Beamforming focuses a wireless signal in a specific direction



(Source: www.everythingrf.com/community/what-is-beamforming)

MASSIVE MIMO, THE KEY TO 5G CAPACITY AND THROUGHPUT

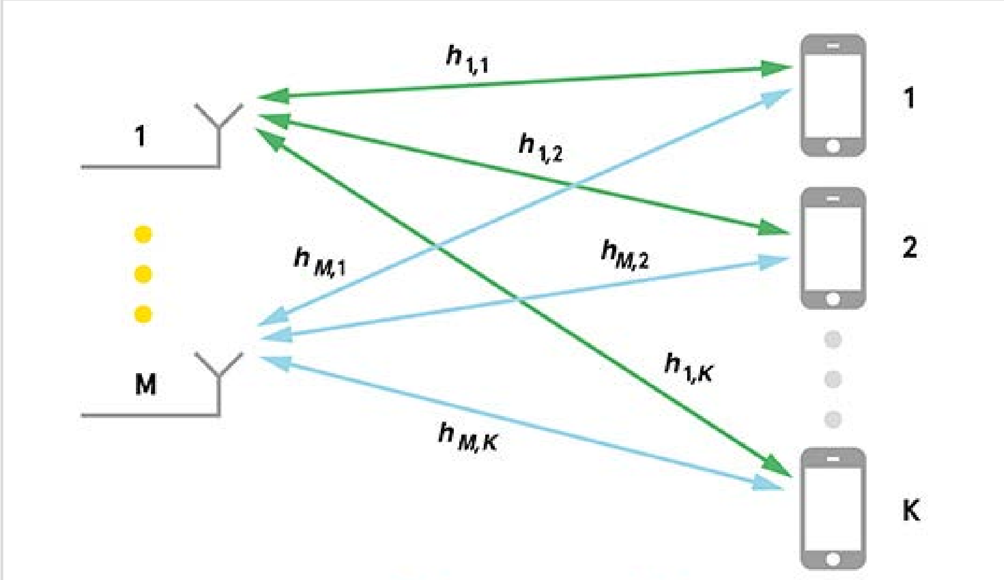
Beamforming is another key wireless technique which works in unison with Massive MIMO to increase network throughput and capacity. Beamforming uses advanced antenna technologies to focus the wireless signal in a specific direction, rather than broadcasting to a wide area. This technique reduces interference between beams directed in different directions, enabling the deployment of larger antennae arrays.

The large number of antennae in a massive MIMO system enables 3D beamforming, which creates both horizontal and vertical beams toward users, increasing data rates (and capacity) for all users – particularly useful in urban areas with high-rise buildings.

Both the network and the connected mobile devices in MIMO systems must be tightly co-ordinated and complex algorithms use spatial information obtained from a Channel State Information Reference Signal, (CSI-RS) to enable the base station to communicate with multiple devices concurrently and independently. The CSI-RS is a type of pilot signal sent out by the base station to the UE, which enables the UE to calculate the Channel State Information (CSI) and report it back to the base station.

The CSI describes how the signal propagates from transmitter to receiver and includes information on how that signal suffers from effects such as scatter, fade and power decay over distance. To recover the transmitted data-stream at the receiver, the MIMO system decoder must perform a considerable amount of signal processing, using the CSI to represent the channel transfer function in matrix form (Figure 3).

Channel State Information used to characterise a massive MIMO system



$$H = \begin{bmatrix} h_{1,1} & \cdots & h_{1,K} \\ \vdots & \ddots & \vdots \\ h_{M,1} & \cdots & h_{M,K} \end{bmatrix}$$

(Source: https://www.analog.com/en/analog-dialogue/articles/massive-mimo-and-beamforming-the-signal-processing-behind-the-5g-buzzwords.html)

MASSIVE MIMO, THE KEY TO 5G CAPACITY AND THROUGHPUT

The channel transfer matrix is defined as **[R] = [H] x [T]**
Where [R] is the series of signals received at the various antennae in the MIMO array, [H] represents the properties of each signal path, and [T] the various data-streams being transmitted across the network.

The decoder constructs the channel transfer matrix by estimating the individual channel properties, h11, h12, etc. from the CSI and the individual data streams are then reconstructed by multiplying the received signal by the inverse of the transfer matrix: **[T] = [H]-1 x [R]**

Estimating the individual channel properties and computing the inverse channel matrix is computationally intensive and can add significant overhead to the network, particularly as the number of antennae grow. The above description is somewhat simplified as there are actually various techniques for acquiring and calculating the CSI which depend upon factors such as the multiplexing techniques used, (TDD or FDD), the signal frequencies, and the amount of movement of the UE. This area is the subject of much ongoing research into how advanced techniques such as neural networking can enhance the reliability and accuracy of massive MIMO.

The Benefits of Massive MIMO
As a key building block of 5G NR, massive MIMO brings multiple benefits to both network operators and end users. The technology significantly improves spectral efficiency, delivering more network capacity for the same amount of spectrum, thereby enabling operators to maximise their investments in this expensive resource.

As 5G networks are rolled out they will depend heavily on network densification in order to deliver the required data rates and to support the high number of connections, particularly in urban areas. Massive MIMO, in conjunction with beamforming technology enables highly targeted use of spectrum, removing current performance bottlenecks, supporting a larger number of users in the cell, and improving end-user experience in densely populated areas. Other potential benefits include higher connection reliability along with increased resistance to interference and intentional jamming, due to the increased number of signal paths. Massive MIMO networks will also be more responsive to devices transmitting at higher frequencies, improving coverage, particularly indoors.

The Future of Massive MIMO
As 5G networks roll out, the use of massive MIMO will expand, with ever larger antennae arrays becoming feasible as the technology and 3GPP specifications evolve. mmWave is the key to 5G performance and capacity, and massive MIMO arrays, which can operate at these frequencies once deemed to be prohibitively complex and costly, will soon become mainstream. NEC, for example, has developed a prototype 24-antenna array capable of operating at 28 GHz, and commercial massive MIMO systems, with 64 arrays of more, will soon be mainstream at both sub-6 GHz and mm Wave frequencies.

These deployments will be facilitated by the parallel evolution of Advanced Antenna Systems (AAS), which integrate the antenna arrays along with the associated RF transmission hardware and software and the signal processing capability required by beamforming and MIMO. As mmWave shrinks the size of the antennae and also the electronic components, these AAS will become smaller, playing a key role in network densification, and being deployed to provide 5G coverage in indoor locations.

5G BEAMFORMING - AN ENGINEERS OVERVIEW

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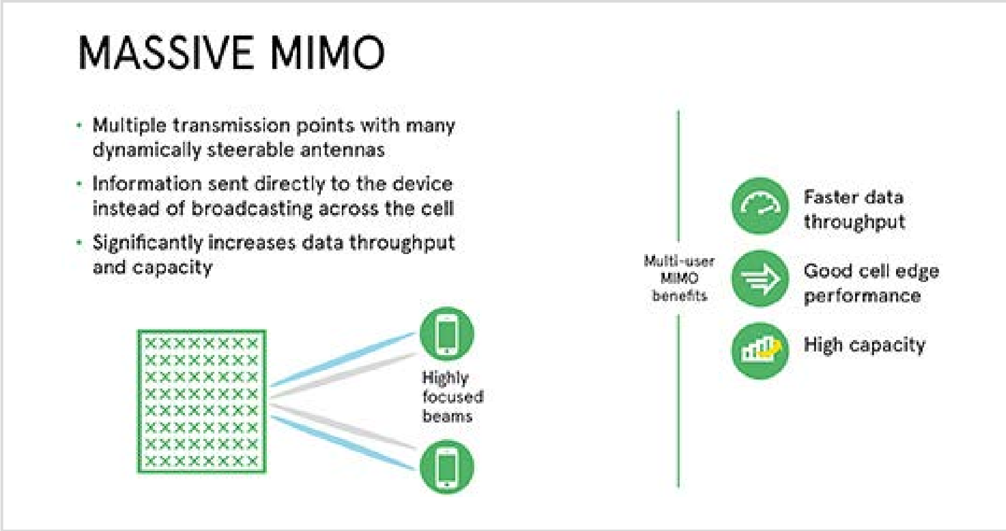
5G delivers a step change in network performance over current 4G levels, with peak data rates up to 20 times faster at 20 GB/s, and connection densities of 1000 devices per square kilometre, 100 times more than 4G. This performance improvement is delivered by 5G New Radio (NR), which uses a number of advanced techniques including mmWave (between 30 and 300 GHz), frequency transmissions, advanced signal coding techniques (OFDM), multi-access edge computing (MEC), and network slicing. Two technologies in particular, massive MIMO and beamforming, are fundamental to 5G's enhanced throughput and capacity and work so closely together that they are often described interchangeably. Both are, in fact, complex techniques, meriting separate descriptions and, with massive MIMO described previously, this article concentrates on beamforming.

Beamforming and Massive MIMO

Beamforming and MU MIMO work together to deliver 5G's demanding throughput and connection densities (Figure 1). Massive MIMO (multiple input multiple output) uses multi-antennae arrays and spatial multiplexing to transmit independent and separately encoded data signals, known as "streams", enabling simultaneous communications with multiple user equipment (UE) over the same time and frequency resource.

Beamforming is used in tandem with MIMO to focus the beams more tightly towards individual UE, enabling higher connection densities and minimising interference between individual beams.

Massive MIMO and beamforming



(Source: Ericsson)

5G BEAMFORMING - AN ENGINEERS OVERVIEW

Beamforming Overview

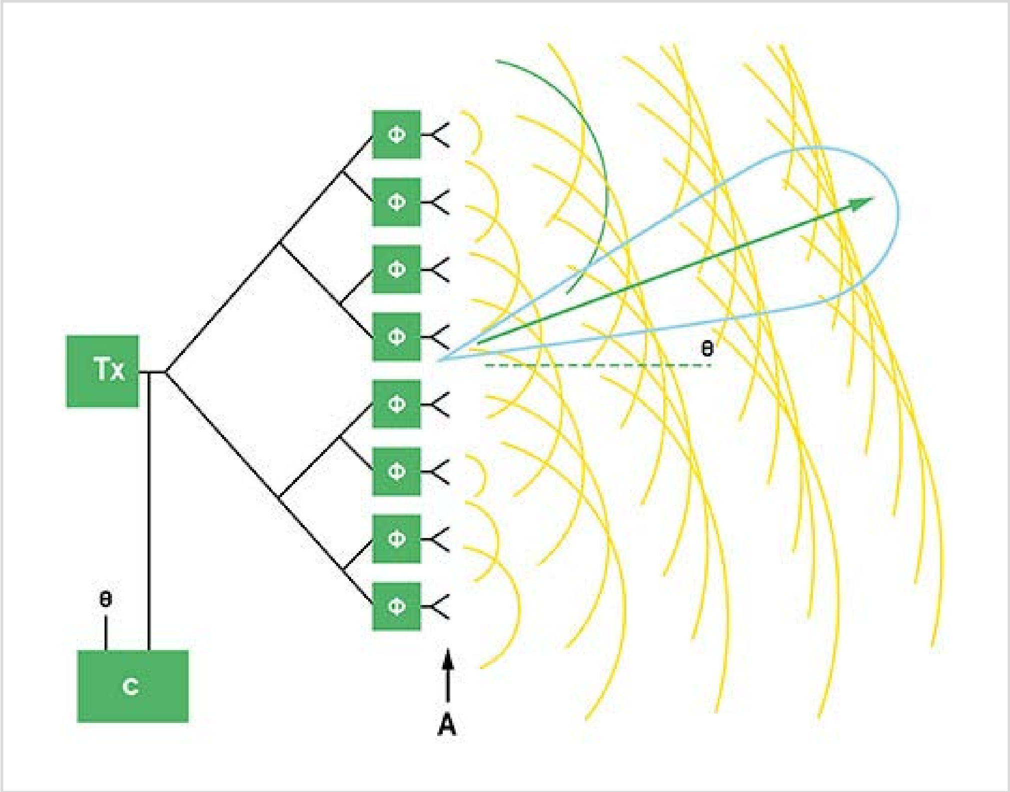
As discussed, beamforming is used with phased array antennae systems to focus the wireless signal in a chosen direction, normally towards a specific receiving device. This results in an improved signal at the user equipment, (UE) and also less interference between the signals of individual UEs.

Phased antenna arrays are designed such that the radiation patterns from each individual element combine constructively, with those from neighbouring elements forming an effective radiation pattern, the main lobe, which transmits energy in the desired direction. At the same time, the antenna array is designed such that signals in undesired directions destructively interfere with each other, forming nulls and side lobes. The overall antenna array system is designed to maximize the energy radiated in the main lobe, whilst limiting the energy in the side lobes to an acceptable level.

The direction of the main lobe, or beam, is controlled by manipulating the radio signals applied to each of the individual antennae elements in the array. Each antenna is fed with the same transmitted signal but the phase and amplitude of the signal fed to each element is adjusted, steering the beam in the desired direction (Figure 2).

Fast steering of the beam is achievable since the phase and amplitude of each signal are controlled electronically, allowing adjustments to be made in nanoseconds.

Phased array antenna systems enable beamforming and steering

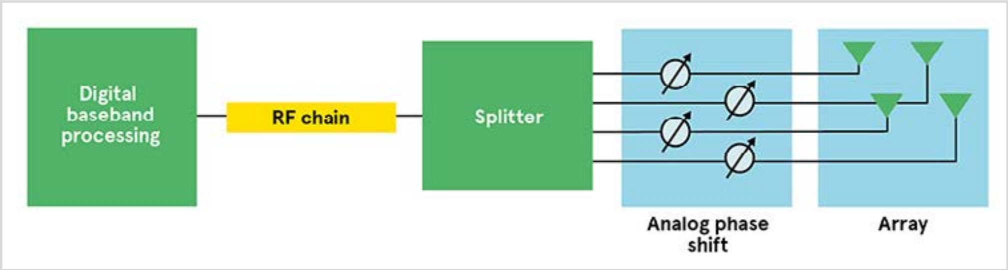


(Source: https://www.analog.com/en/analog-dialogue/articles/phased-array-beamforming-ics-simplify-antenna-design.html)

5G BEAMFORMING - AN ENGINEERS OVERVIEW

Analogue, digital and hybrid beamforming
There are three methods of implementing antenna beamforming:
Analogue beamforming (Figure 3) is the simplest method, with the signal phase being changed in the analogue domain. The output from a single RF transceiver is split into a number of paths, corresponding to the number of antenna elements in the array. Each signal path then passes through a phase shifter and is amplified before reaching the antenna element.

Analogue beamforming

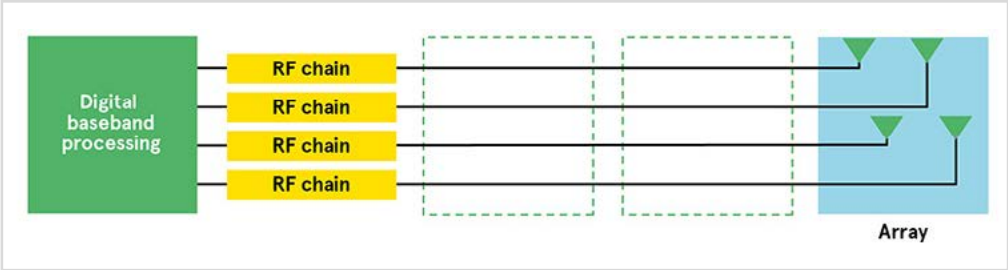


(Source: www.commscope.com/globalassets/digizuite/542044-Beamformer-Explained-WP-114491-EN.pdf)

This is the most cost-effective way of implementing beamforming, since it uses a minimal amount of hardware, however an analogue beamforming system can only handle one data stream and generate one signal beam, limiting its effectiveness in 5G, where multiple beams are required.

In digital beamforming, each antenna element is fed by its own transceiver and data converters (Figure 4) and each signal is pre-coded (with amplitude and phase modifications) in baseband processing before RF transmission.

Digital beamforming



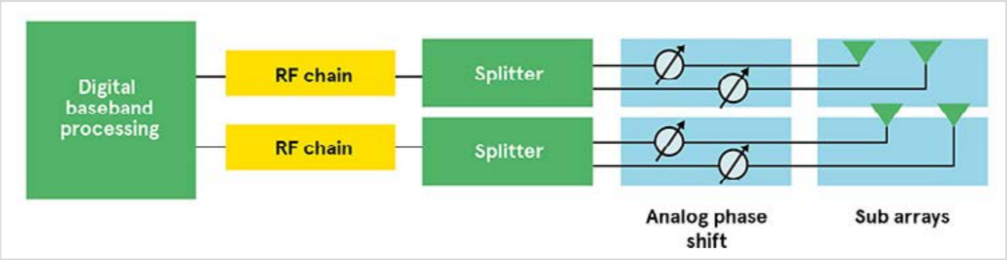
(Source: www.commscope.com/globalassets/digizuite/542044-Beamformer-Explained-WP-114491-EN.pdf)

Digital beamforming enables several sets of signals to be generated and superimposed onto the antenna array elements, enabling a single antenna array to serve multiple beams, and hence multiple users. Although this flexibility is ideal for 5G networks, digital beamforming requires more hardware and signal processing, leading to increased power consumption, particularly at mmWave frequencies, where several hundred antenna elements are possible.

Hybrid beamforming (Figure 5) where analogue beamforming is carried out in the RF stage, and digital beamforming in the baseband, offers a compromise between the flexibility of digital beamforming and the lower cost and power consumption of analogue.

Hybrid beamforming (Figure 5) where analogue beamforming is carried out in the RF stage, and digital beamforming in the baseband, offers a compromise between the flexibility of digital beamforming and the lower cost and power consumption of analogue.

Hybrid beamforming



(Source: www.commscope.com/globalassets/digizuite/542044-Beamformer-Explained-WP-114491-EN.pdf)

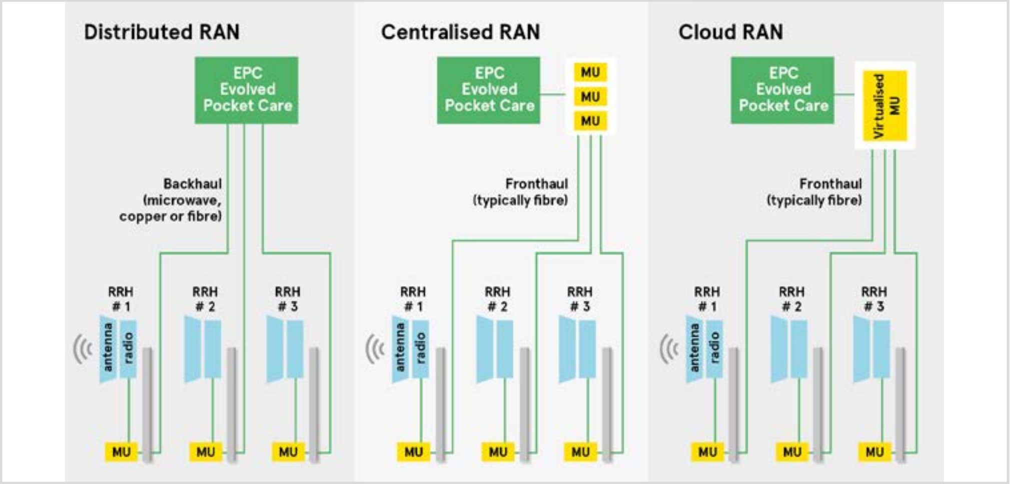
Hybrid beamforming is recognised as a cost-effective solution for large-scale, mmWave antenna arrays and various architectures are being developed for gNB, (5G base station) implementations. These architectures divide broadly into fully connected, where each RF chain is connected to all antennas; and sub-connected or partially connected, in which each RF chain is connected to a set of antenna elements. Each architecture aims to reduce the hardware and signal processing complexity while providing the near optimal performance, i.e., the closest to that of pure digital beamforming.

In all architectures, communication between the gNB and the UE is co-ordinated using a technique known as beam sweeping, along with Synchronisation Signals, (SS), and Channel State Information, (CSI), obtained via a Channel State Information Reference Signal, (CSI-RS), a type of pilot signal sent from the gNB to the UE.

In beam sweeping, the gNB transmits bursts at regular intervals in different spatial directions. The UE listens for these bursts and uses the CSI to determine a channel quality associated with each one.

This quality information is used by the UE to select the optimal beam from its point of view and the UE informs the gNB of this choice. The UE and the gNB exchange other information, such as analogue or digital beamforming capabilities, beam-forming type, timing information, and configuration information, adding to the overhead on the channel. Hybrid beamforming, with its partitioning of digital and analogue beamforming aligns well with ongoing developments to disaggregate and virtualise the RAN. Centralized RAN, (C-RAN), splits the base stations into low power and low complexity remote radio heads (RRHs) coordinated by a central unit (CU) located at the central office (CO) (Figure 6). Sharing baseband resources across multiple RRHs makes C-RAN architectures both cost-effective and energy-efficient, making them an attractive option for network densification.

5G networks are moving to a Centralized RAN Structure



(Source: Nokia)

Additionally, removal of the baseband functionality facilitates the deployment of smaller RRHs, which can be flexibly deployed at locations such as lamp posts, electricity pylons and building corners, again supporting network densification and so on.

Benefits of beamforming

Beamforming effectively uses the science of electromagnetic interference to enhance the precision of 5G connections, working in tandem with MIMO to improve throughput and connection density of 5G network cells. The resultant highly directional transmissions are particularly beneficial with mmWave transmissions, which suffer heavily from path loss and do not propagate well through obstacles such as walls. The improved Signal-to-Noise Ratios, (SNR), enabled by beamforming, increase signal range for both outdoors and, importantly, indoor coverage.

Beamforming's ability to cancel out, or "null", interference is also a significant benefit in crowded, urban environments with high densities of UEs, where multiple signal beams can potentially interfere with each other. Overall, by reducing internal and external interference and reducing SNR, beamforming supports higher order signal modulation schemes, such as 64QAM and 16QAM, all of which contribute to a substantial improvement in network cell capacity.

Futures and challenges facing beamforming technology

In common with many other areas of 5G networks, developers of antenna systems must meet the twin demands of ever shrinking components and reduced power consumption. The pressure to increase spectral efficiency and throughput is leading to the specification of ever larger antenna arrays, with 64 x 64 MIMO, and larger already on the horizon.

The effectiveness of beamforming is heavily dependent upon the precision of the antenna arrays, with the strength of unwanted sidelobes increasing as the spacing between elements approaches the signal wavelength. At 60 GHz this wavelength is 5mm, giving some idea of the manufacturing tolerances required.

Shrinking wavelengths also mean shrinking components, such as RF transceivers, which must integrate RF power amplifiers with functionality such as ADCs, At the same time designers must find ways of improving power efficiency of all 5G network components. RF power amplifiers for mmWave have traditionally been the preserve of III-V semiconductor materials such as GaAs, however these devices are not sufficiently power efficient and do not integrate well with other functionality. Advances in 40 nM CMOS are therefore welcome, enabling the size and power consumption of these key components to continue to shrink.

Also, as more beams are generated by individual gNBs, the signal processing requirements become more complex. This is an ongoing area of research and development into areas such as beam synchronisation, with neural network techniques being deployed, requiring advanced processing hardware, further stretching power budgets, and adding space constraints.

Conclusion

The 5G promise relies on a successful roll-out of mmWave technology and both MIMO and beamforming are critical components, enabling the capacities and throughputs required by emerging applications and exponentially growing numbers of IoT devices.

In a few short years MIMO and beamforming have moved out of the research environment into commercial deployment, first in LTE networks and now in early 5G deployments. 3GPP specifications place heavy demands on the continued evolution of these twin functions, and ongoing developments in supporting technologies such as Advanced Antenna Systems, (AAS), 40 NM CMOS and software processing pave the way for ever larger MIMO arrays.

/ UNDERSTANDING ADVANCED ANTENNA SYSTEMS

UNDERSTANDING ADVANCED ANTENNA SYSTEMS

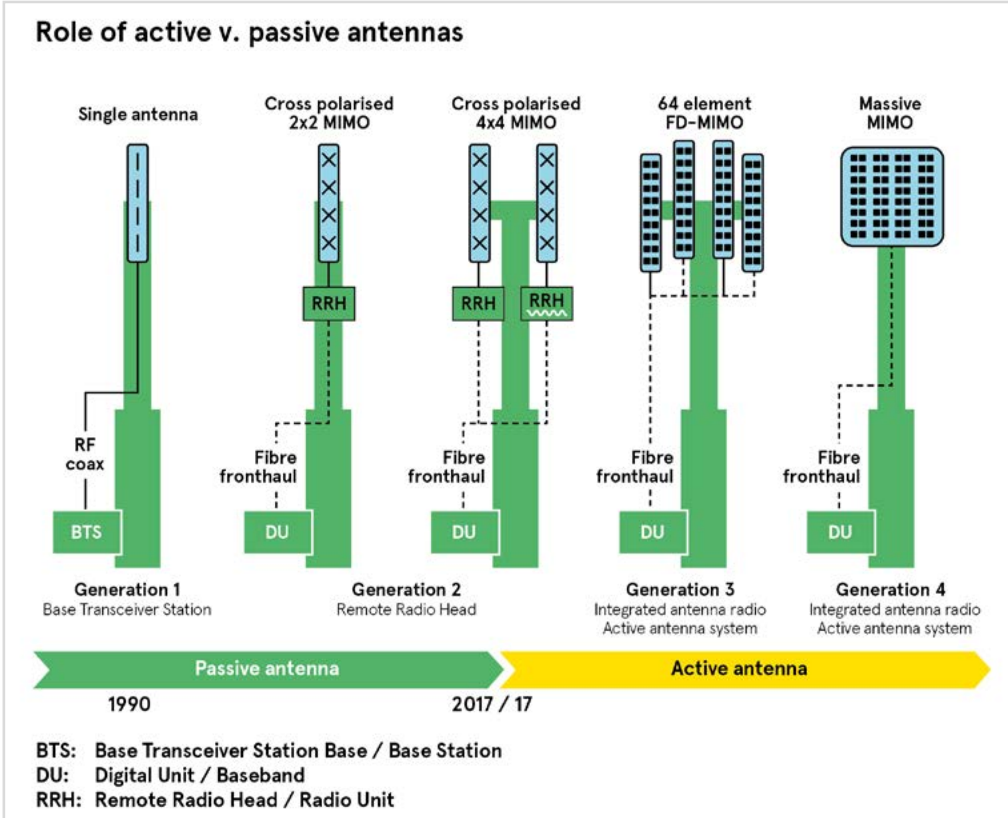
As capacity, coverage and connection density requirements grow, Mobile Network Operators, (MNOs) have incorporated advanced technologies such as massive MIMO and beamforming into their networks. In parallel, Advanced Antenna Systems, (AAS), have evolved to integrate these technologies and enable their deployment in the wireless infrastructure.

Deploying the most suitable AAS variant requires an understanding both of AAS technologies and also the specific requirements of the network. This guide provides an introduction to AAS, covering what they are, how they work, and their benefits and design challenges.

What are Advanced Antenna Systems?
Recent advances in technologies such as massive MIMO and beamforming are key to the improved capacity and throughput achievable with 5G NR. As the size of massive MIMO antenna arrays have grown, however, conventional antennae struggle to support them due to weight, space and power consumption limitations. In a conventional antenna, for example, the RF electronics and the passive antenna are physically separate. With 100 or more antenna elements in modern arrays, it becomes unwieldy and inefficient to use separate RF cables to connect them. AAS have evolved in parallel with MIMO array developments (Figure 1) leveraging advances in integration and miniaturization techniques to enable the effective deployment of 5G NR within MNOs' network infrastructures.

An AAS combines an AAS radio with a set of AAS features, which include MIMO and beamforming. A core component of the AAS is an active antenna system, where the active transceiver array and the passive antenna array are intelligently integrated into a single hardware unit. This integration enables significant miniaturization of the AAS whilst enhancing communication throughput and reducing cable losses and power consumption. The AAS also includes the hardware and software required for the signal processing radio signals and the algorithms to support the execution of the AAS features.

Evolution of antennae



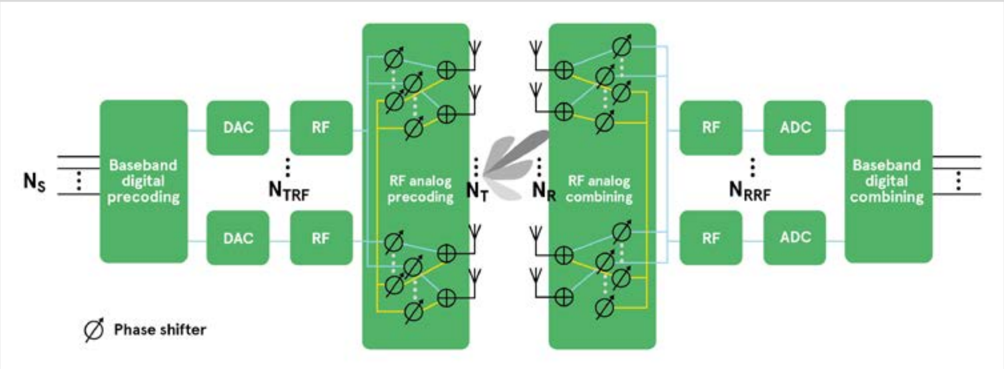
(Source: www.rcrwireless.com/20180624/wireless/analyst-angle-the-rise-and-outlook-of-antennas-in-5g)

UNDERSTANDING ADVANCED ANTENNA SYSTEMS

How they work
The operation of an AAS is based on a rectangular antenna array, where beam-forming is used to steer high gain beams at a range of angles. The antenna array is designed such that individual elements combine constructively to form a main lobe which transmits energy in a given direction, with the overall gain of the system dictated by the number of elements in the array. The RF signals to be transmitted are individually pre-coded, with phase and amplitude shifts, before being applied to the individual array elements, enabling them to be steered in the desired direction. The use of dual-polarized array elements, which respond simultaneously to both horizontally and vertically polarized radio waves, increases the traffic handling capacity of the system. Each element is fed by two independent transceivers, with one set on vertical polarization and the other on horizontal polarization.

In practical AAS implementations, multiple antenna elements are partitioned into subarrays, with each subarray being fed with its own RF chain (Figure 2). This hybrid implementation requires fewer RF chains, reducing the complexity, cost, and power consumption of the overall array.

Hybrid beamforming example with RF and digital steering

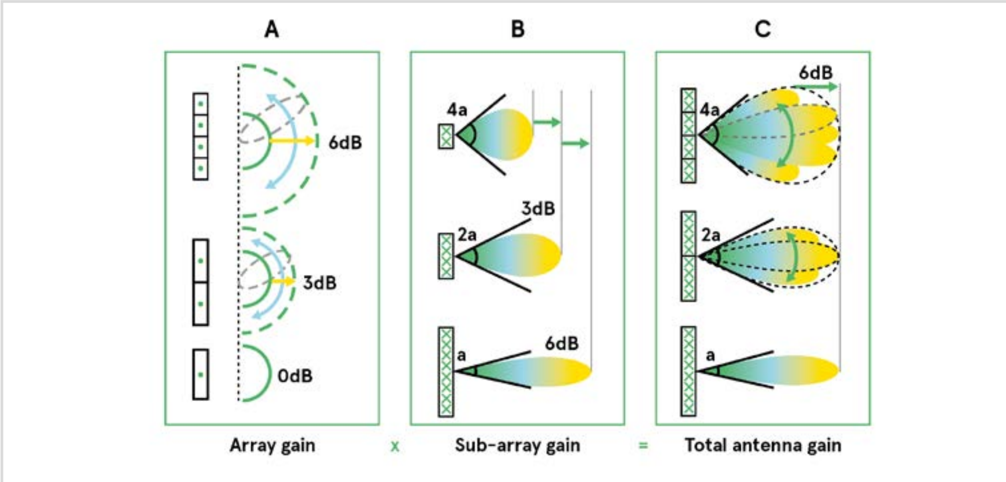


(Source: MathWorks)

The characteristics of the antenna array are determined by the way in which its arrays are partitioned into an array of subarrays (AOSA). The total antenna gain obtained when all subarray signals are added constructively, in phase, is dependent upon the number of subarrays. Two subarrays, for example, double the gain achieved over a single subarray, i.e. a gain of 3 dB (Figure 3A). Likewise, four subarrays add a further 3 dB but, as the size of the subarrays increase, the emitted beam becomes narrower (Figure 3B). The total gain of the antenna system is the product of the array gain and the subarray gain, as shown in Figure 3C.

In summary, the maximum gain of the antenna is determined by the number of antenna elements in the array, and the way in which the subarrays are partitioned enables steering of high gain beams over a range of angles (Figure 3C). At the same time, the subarray radiation pattern determines the envelope of the emitted beams, as shown by the dotted lines in Figure 3C.

AOSA partitioning supports high antenna gain and steerability



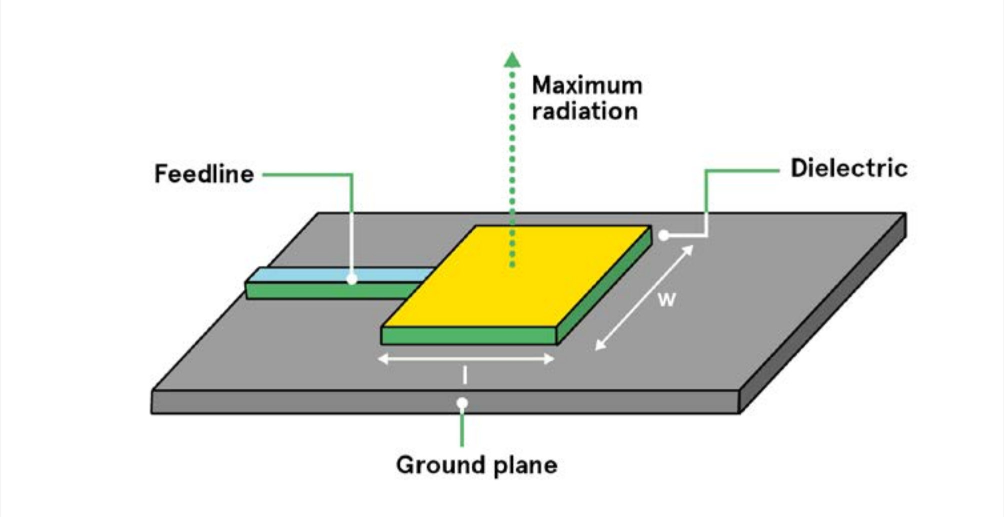
(Source: www.ericsson.com/en/reports-and-papers/white-papers/advanced-antenna-systems-for-5g-networks)

UNDERSTANDING ADVANCED ANTENNA SYSTEMS

Note that, although the above description has focused on one dimension, the same principles actually apply in both the horizontal and vertical dimensions where dual polarized antenna elements are used.

Enabling technologies
Integrated antenna arrays have been enabled by improved antenna manufacturing techniques as well as developments in semiconductor technology. Antenna design has moved on from traditional plank architectures to flat panel configurations which use patch antennae as building blocks. A patch antenna (Figure 4) consists of a flat rectangular conductor (the patch) mounted over a larger flat conductor (the ground plane) with a dielectric material separating the patch and ground plane.

The patch antenna



(Source: www.5gtechnologyworld.com/antenna-elements-combine-in-phased-array-antennas/)

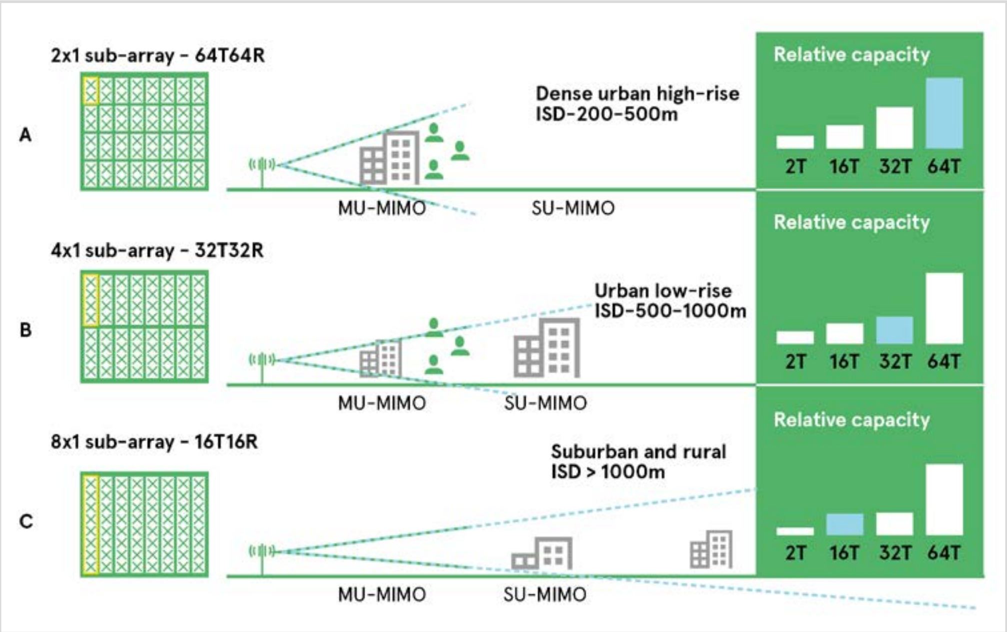
Patch antennae are becoming more commonly used as the wavelengths of wireless transmissions shrink. The resultant, smaller antenna geometry in turn enables the construction of antenna arrays with higher multiples of elements, leading to correspondingly higher gains. Along with these developments in antenna design, advances in semiconductor technology have enabled the antenna electronic components, such as RF transceivers, power amplifiers, ADCs, filters, and switches, to be packed into smaller ICs, which can fit onto the rear of the antenna board, significantly reducing the depth of the antenna. With massive MIMO arrays becoming larger and beamforming techniques more sophisticated, advanced Channel State Information (CSI) mechanisms are required to support the beam management processes. The complex software algorithms which operate on this CSI are enabled by artificial intelligence (AI) techniques, such as neural networks, which in turn are enabled by powerful custom ICs.

Active vs passive antennae
Whilst this discussion has focused on advanced digital antenna arrays, there is still a clear role for passive antennae. These systems have also evolved significantly in recent years and are now capable of supporting 4 x 4 and even 8x8 MIMO. With many initial 5G deployments in the coverage and capacity "sweet spot" of 3.5 GHz, the full capabilities of AAS may not be required, especially in non-urban areas where capacity and user numbers are not constraints. In these scenarios the benefits of AAS may not justify the costs, and passive systems could provide a viable alternative. Legacy networks, which will co-exist with 5G for many years to come, also use frequencies in the lower ranges, and passive antennae can be deployed to continue to support these networks.

Also, at cell sites which must deliver both 5G and continue to support legacy networks, the smaller sizes of modern antennae make it feasible to house both active and passive systems under the same radome, potentially saving on site costs and space.

Deployment scenarios
When choosing the optimum AAS configuration for a particular cell site, consideration should be given to the environment that it will be serving, with key factors including the number of users to be served, the inter-site-distances (ISDs), and the nature of the buildings and locations to be covered. The following three scenarios, illustrated in Figure 5, show how some of these factors influence the choice of antenna design.

Suitable AAS configurations for a range of network deployment scenarios



(Source: www.ericsson.com/en/reports-and-papers/white-papers/advanced-antenna-systems-for-5g-networks)

Scenario A: Dense urban high-rise
Dense urban areas with high rise buildings and large traffic volumes require large antennae arrays to ensure sufficient coverage. Partitioning the array into small subarrays gives high-gain beams that can be steered in a wide range of angles, catering for the vertical spread of users. MU-MIMO is important in this environment and the high number of small partitions requires a sufficient number of radio chains, with 64 being a good trade-off between complexity and performance.

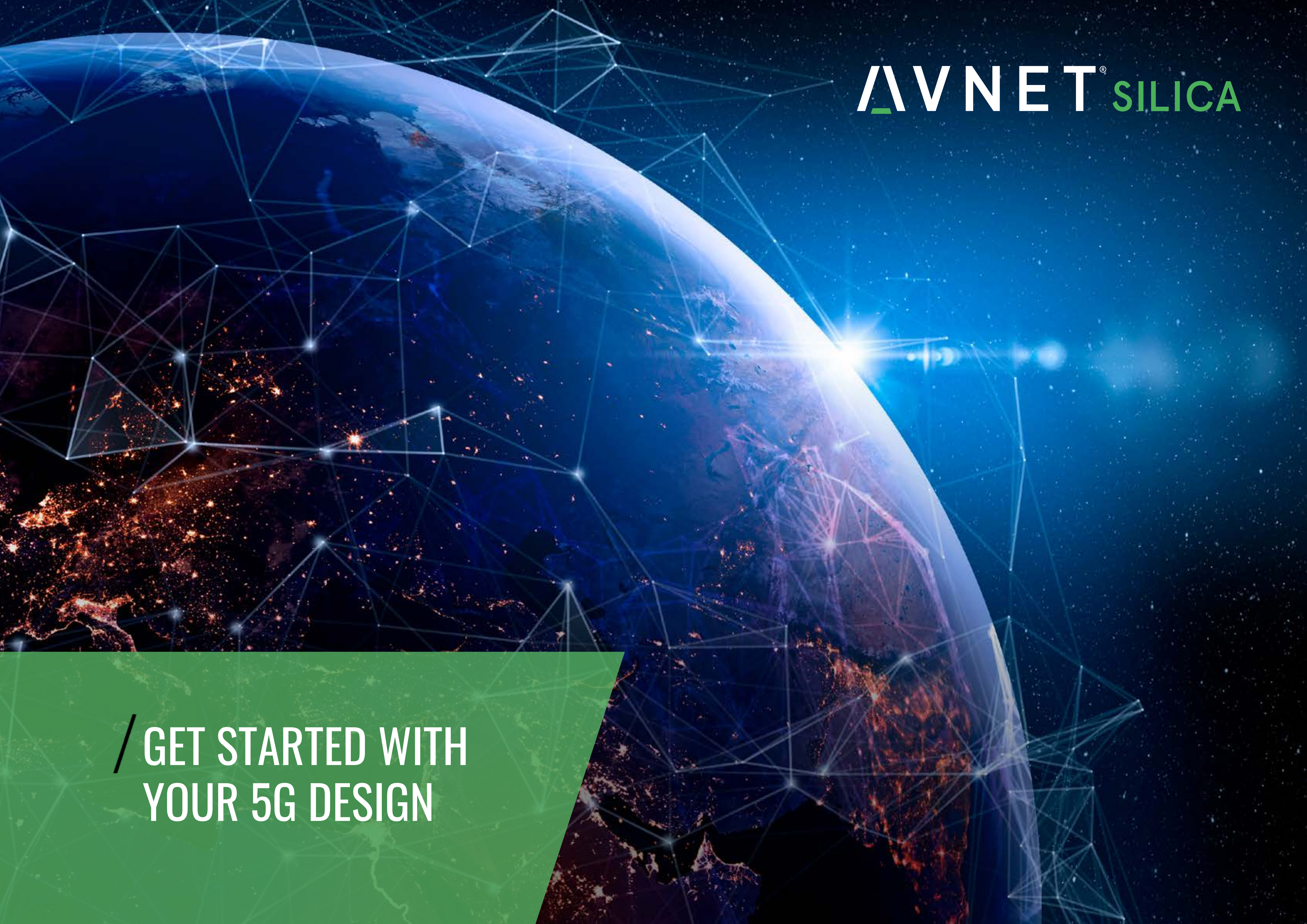
Scenario B: Urban low-rise
Representative of many of the world's large cities, with lower traffic densities, a mix of building types and less vertical spread of users. In this scenario a large antenna area is required to deliver the required cell data-rates, but vertical coverage range can be decreased, so larger vertical subarrays can be used. MU-MIMO is still important here, but, with the smaller number of subarrays, 16 – 32 radio chains are optimal.

Scenario C: Rural/suburban
Characterized by low or medium population densities, small, vertical user distributions and inter-site distances from one to several kilometres. Again, a large antenna array is required for coverage, but vertical beamforming is not a priority so large vertical sub-arrays are ideal. MU MIMO benefits are limited due to the low user population, therefore 8 to 16 radio chains give an optimum compromise.

AAS benefits, trade-offs, and considerations
This article has described the principles of operation of AAS and the many benefits that they can bring to wireless networks, when appropriately deployed. The massive MIMO capabilities of AAS are most suited to scenarios with dense user populations and high traffic volumes where MNOs must maximise use of spectrum. The small wavelengths of mmWave transmissions enable even smaller antennae, which are ideal for network densification in these areas.

AAS are not, however, a panacea for all network deployments. MNOs must focus their investments to ensure maximum returns, and the business case varies significantly across the scale from urban to rural environments, where the sparse populations may not justify the relatively high costs of AAS. Also, legacy networks will co-exist with 5G for many years to come, and, in both cases advanced passive antenna systems may be the optimal solution. These, and other factors, require careful consideration when rolling-out 5G networks.

Get started with your design
Our technical specialists can help you with design advice. **Contact them here.**



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