Impacts of mmWave 5G in China

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Contents

Introduction

5G's higher speeds and lower latencies enable new applications that were previously unattainable under earlier generations of mobile technology. These 5G networks need a combination of spectrum in three ranges—sub-1 GHz, 1-6 GHz, and above 6 GHz — to fully maximize their capabilities. Each range offers distinct performance characteristics that will help China deliver on its vision for 5G. The assignment of 5G mmWave spectrum in the latter range, between 24 GHz and 86 GHz, will provide the increased bandwidth and capacity that numerous 5G applications require. This spectrum range is expected to play a key role in meeting the demand for enhanced mobile data services as well as new use cases.

Quickly becoming a 5G leader, China announced one of the first commercial deployments in 2019.[1] Building on this momentum, it is now actively considering the best regulatory approaches to develop and promote the 5G ecosystem, making it an interesting subject for a more in-depth look at the potential impact of mmWave 5G. At this stage, China should take into consideration recent international activities. For instance, at the International Telecommunication Union (ITU) World Radiocommunication Conference in 2019 (WRC-19), mmWave bands between 24 GHz and 86 GHz were identified for International Mobile Telecommunications (IMT). They include the 24.25-27.5 GHz, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.3 GHz, and 66-71 GHz bands. Approximately 85% of this spectrum is globally harmonised, a solid step towards achieving the best performance and economies of scale from mmWave 5G.[2]

To maximise the benefits of mmWave 5G, certain regulatory measures are essential. Mobile network operators (MNOs) require reliable and predictable access to licensed spectrum on a long-term basis to justify the substantial investments necessary to deploy networks. For mmWave spectrum, Chinese regulators should consider assigning around 1 GHz of contiguous spectrum per operator, which can provide the added capacity needed to support data-intensive applications.

Additionally, when considering potential alternatives like spectrum set-asides and mandated sharing regimes, Chinese policymakers should carefully reflect on how these approaches may impact the success of 5G services. It will be important to ensure that spectrum is not at risk of being underutilised and that the assignment of spectrum does not undermine MNOs' ability to deliver the full range of 5G capabilities, including support for industrial applications. Striking the right balance to enable 5G industrial applications across different industry verticals while at the same time ensuring MNOs' predictable access to spectrum will be important to promote the provision of widespread, quality 5G services and applications.

New use cases will be the driving force behind mmWave 5G advances and the significant socio-economic benefits enabled by the technology. Given the dominance of manufacturing in China's economy, industrial applications leveraging mmWave 5G present a great opportunity for China to drive economic growth. Across case studies on Industry 4.0 and transportation, this report further details the opportunities that lay ahead.

KEY TAKEAWAYS

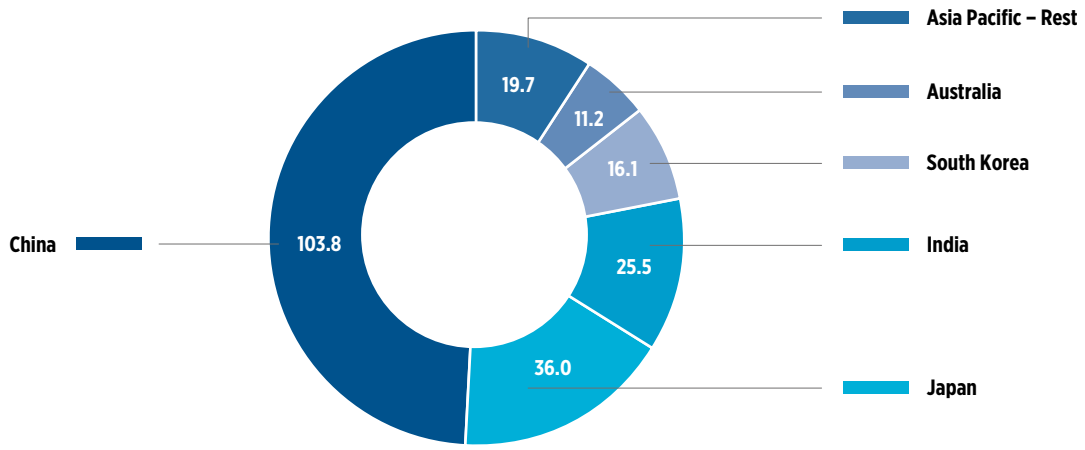
- **Regulators should assign large, contiguous blocks of mmWave spectrum to support data-intensive 5G applications.**
- **MNOs must have predictable long-term access to licensed spectrum to safeguard network investment and meet speed and capacity targets.**
- **Spectrum set-asides and mandated sharing regimes should be considered carefully to avoid spectrum underutilisation, the undermining of fair spectrum awards, and decreased 5G service quality.**

1. BBC (2019), "China rolls out 'one of the world's largest' 5G networks," https://www.bbc.com/news/business-50258287.
2. ITU (2019), "WRC-19 identifies additional frequency bands for 5G," https://news.itu.int/wrc-19-agrees-to-identify-new-frequency-bands-for-5g/.

2. Potential benefits of mmWave in China

China is an early adopter of 5G, with initial deployments of commercial 5G services announced in 2019. As a 5G frontrunner, China is similarly expected to utilise mmWave bands in its 5G networks. Estimates of the economic benefit arising from the use of mmWave bands in China place the impact at approximately $104 billion by 2034. This represents approximately half of the estimated contribution from mmWave bands in the Asia-Pacific region, which is expected to reach $212 billion.[3] Other expected early adopters in the region include Australia, India, Japan, and South Korea. These countries, along with China, comprise around 90% of the region's GDP contribution attributable to mmWave 5G (see Figure 1).

FIGURE 1. STRUCTURE OF mmWAVE 5G GDP CONTRIBUTIONS FOR ASIA-PACIFIC BY 2034

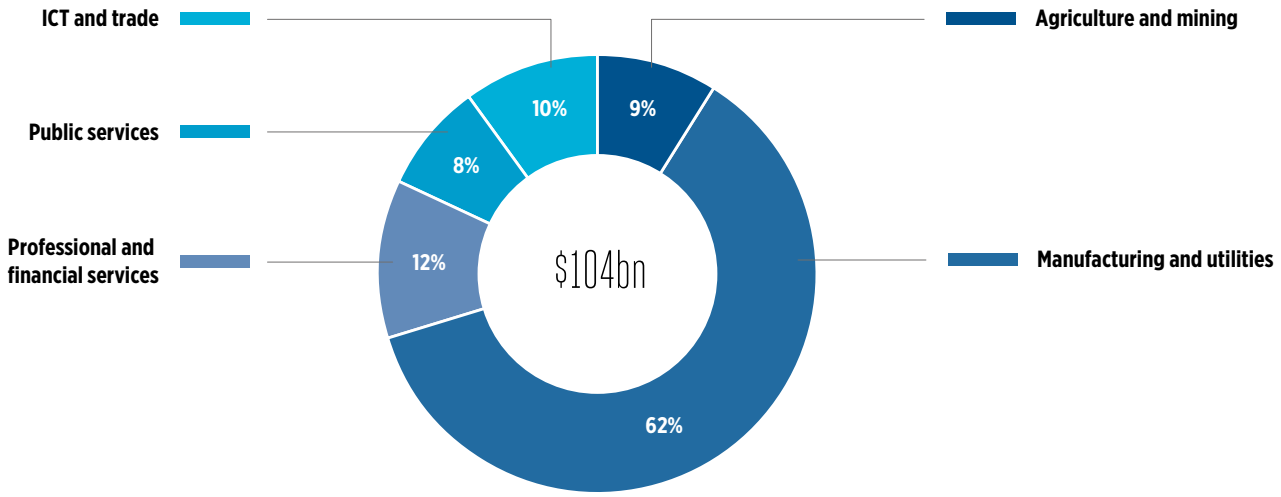


Source: GSMA and TMG (2018), "Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands," https://www.gsma.com/spectrum/wp-content/uploads/2019/01/5G-mmWave-benefits.pdf

Considering the expected mmWave 5G contributions to China's GDP, the manufacturing and utilities vertical is by far the largest contributor, comprising 62% of the total. This is followed by professional and financial services at 12%, ICT and trade at 10%, then agriculture and mining, and lastly public services (see Figure 2). Given China's global manufacturing importance, the dominance of the manufacturing sector on China's GDP is to be expected. This economic prominence, combined with the numerous potential industrial applications of mmWave 5G, contributes to the vertical's significant impact on GDP as the use of mmWave 5G grows.

1. These figures were based on the 2018 GSMA report, Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands, which studied the socio-economic impact of mmWave spectrum over a 15-year period (2020-2034). For more information, read the full report at https://www.gsma.com/spectrum/wp-content/uploads/2019/01/5G-mmWave-benefits.pdf. The figures reported are cumulative over the 15-year period, ending in 2034.

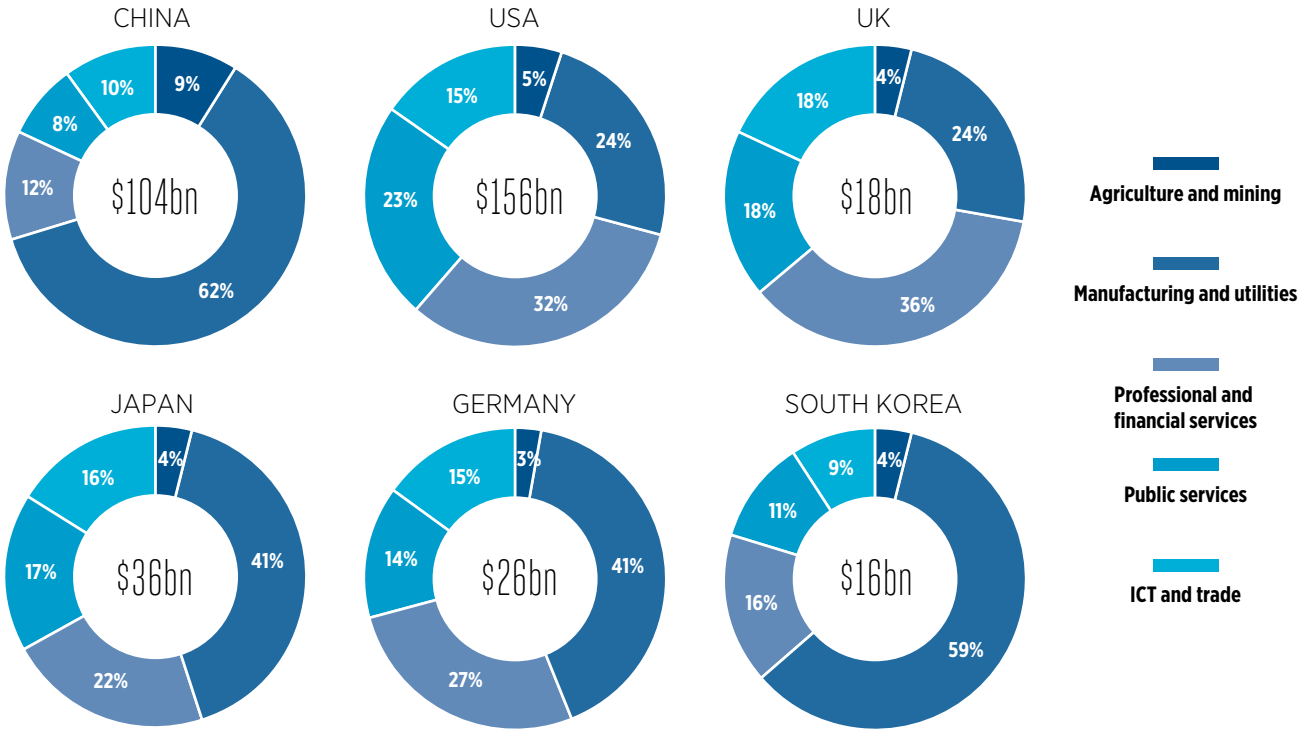
FIGURE 2. STRUCTURE OF mmWAVE 5G GDP CONTRIBUTIONS BY VERTICAL IN CHINA IN 2034



Source: TMG, based on the GSMA and TMG (2018), "Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands," https://www.gsma.com/spectrum/wp-content/uploads/2019/01/5G-mmWave-benefits.pdf.

Compared to other countries expected to lead 5G deployments worldwide, such as Germany, Japan, South Korea, the United Kingdom, and the United States, China's expected contribution of mmWave 5G to domestic GDP is second only to the United States', with $104 billion compared to $156 billion, respectively (see Figure 3). In China, Germany, South Korea, and Japan, the manufacturing and utilities sector contributes the largest proportion of national GDP attributable to mmWave 5G, while the professional and financial services vertical is the largest contributor in the US and the UK.

FIGURE 3.CHINA'S mmWAVE 5G GDP CONTRIBUTION COMPARED TO OTHER LEADING 5G NATIONS



Source: TMG, based on the GSMA and TMG (2018), "Study on Socio-Economic Benefits of 5G Services Provided in mmWave Bands," https://www.gsma.com/spectrum/wp-content/uploads/2019/01/5G-mmWave-benefits.pdf.

3. mmWave 5G technical considerations in China

3.1. 5G spectrum requirements

5G is more than just a faster 4G technology. It allows for greater diversification of use cases, including ultra-reliable low-latency applications and support for a variety of Internet of Things (IoT) services. This also requires a diversification of spectrum – a combination of low, medium, and high bands – so that spectrum is used for the services or applications where it provides the greatest value. With 5G, each range of bands plays a different role in the overall 5G ecosystem, allowing MNOs to provide the right mix of coverage and capacity. Furthermore, 5G will enable new services and devices, provide connectivity to new sectors, and leverage new user experiences.

Recognising the importance of this combination of different spectrum bands, China has already taken strides to promote the initial stages of 5G deployment, especially with sub-6 GHz band spectrum. In December 2018, China's Ministry of Industry and Information Technology (MIIT) granted China Telecom, China Mobile, and China Unicom the right to use frequencies to test 5G networks across the 2.6 GHz, 3.5 GHz and 4.8 GHz bands. The following June, MIIT issued 5G commercial licenses to them and to a new player, China Broadcasting Network, to allow the commencement of commercial 5G services nationwide.[4]

During WRC-19, two mmWave 5G bands received the most support from member countries – the 24.25-27.5 GHz and 37-43.5 GHz ranges. The agreement reached at WRC-19 also set out-of-band emissions limits for the 24.25-27.5 GHz band, which is now driving the standardisation and ecosystem for this band. Building upon this foundation, China's next step is to consider how to incorporate mmWave bands into their national 5G spectrum policy frameworks, including in the assignment process. China took a pro-investment stance with the direct assignment of the 2.6 GHz, 3.5 GHz, and 4.8 GHz bands, where no spectrum fees were applicable in the initial years. Other markets in the region have taken similar approaches. In Hong Kong, operators were given direct licenses in the 26 GHz and 28 GHz bands and will not pay spectrum fees until both bands reach 75% occupancy.[5] Similarly, in Japan, the Ministry of Internal Affairs and Communications (MIC) assigned spectrum in the 3.7 GHz, 4.5 GHz, and 28 GHz bands to operators in exchange for network investment and deployment commitments.[6] Following these examples, China should either assign the mmWave band spectrum through a direct assignment without any fees or at least waiving the fees for the initial years as previously done for other spectrum bands. Another possible option would be to accept in-kind considerations (e.g., deployment commitments) in exchange for the spectrum. Taking one of these three assignment approaches will best encourage investment and network deployment.

Harmonisation of spectrum bands remains important for 5G networks, as does the availability of sufficient spectrum per operator in each frequency range. For example, the ITU IMT vision of what a 5G network should provide indicates that mobile broadband systems enhanced with 5G should achieve a data transmission capacity of 10 Gbps. This scenario would likely be a hotspot with limited coverage and thus better provided by bands above 24 GHz. In broad urban and suburban coverage areas, 5G is expected to offer a user experience at speeds of 100 Mbps, which is best suited for bands below 6 GHz.[7] Noting that different 5G bands are needed to fulfil certain requirements and take advantage of the full capabilities that 5G networks can provide, each operator in China should have access to a minimum of:

- 80-100 MHz of contiguous mid-band spectrum (e.g., the 3.5 GHz band), and
- a minimum of 1 GHz in mmWave bands.

As such, it is important that China's national regulations are aligned with these international recommendations.

4. Idem and MIIT (2019), "China 5G Development and Policy," https://static1.squarespace.com/static/5bf2b77d75f9eefcd937cb5c/t/5d1a20eb11a9570001f95d65/1561993455970/5.+Julin+LIU.pdf.
5. OFCA (2019), https://www.ofca.gov.hk/filemanager/ofca/en/content_1127/26_28_GHz_Successful_Applicant_Notice.pdf.
6. MIC (2019), "Approval of a plan to open a specific base station for the introduction of the fifth generation mobile communication system, " https://www.soumu.go.jp/menu_news/s-news/01kiban14_02000378.html. MIC (2019), "Approval of establishment plan of specific base station for introduction of 5G mobile communication system (5G) (Overview)," https://www.soumu.go.jp/main_content/000613734.pdf.
7. Recommendation ITU-R M.2083-0 (2015), "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond," pp. 14, https://www.itu.int/rec/R-REC-M.2083-0-201509-I/en.

3.2. Development of the 5G ecosystem

China recognises the importance of the development of a 5G device ecosystem, taking note that 5G chips and modules have not yet achieved industry-wide standardisation.[8] The technical conditions for the use of each of the mmWave bands were agreed at the international level at WRC-19, thus paving the way for their continued standardisation to support the development of the equipment ecosystem.

There are several ongoing 5G-related standardisation efforts. In addition to the ITU's work on International Mobile Telecommunications beyond 2020 (IMT-2020), the Third Generation Partnership Project (3GPP) is updating the specification for the 5G New Radio (5G NR). Originally introduced in Release 15, the specification created a global standard allowing commercial 5G implementations from 2019 onwards.[9] Similar activities, which take into account the work of 3GPP, are under development at the ITU. The process of defining the IMT-2020 specifications should be finalised by the end of 2020.[10]

Some countries and territories in Asia, Europe, and North America have already awarded mmWave 5G licences. According to the Global mobile Suppliers Association (GSA), during 2019, the number of announced 5G devices has grown rapidly, gathering pace as operators in various parts of the world launched their first commercial 5G services. By January 2020, there were more than 200 5G devices announced, a third of which support some of the mmWave bands (26.5-29.5 GHz, 27.5-28.35 GHz, 37-40 GHz, and 66-71 GHz).[11] This indicates that the growing mmWave 5G device ecosystem is ready for implementation in China.

3.3. Addressing the spectrum needs of industry verticals

The Ministry of Industry and Information Technology's "5G + Industrial Internet" plan, issued in December 2019, underscores the government's belief in the promise of industrial 5G applications.[12] Indeed, there is potential for mmWave 5G to bring substantial benefits to China through industrial applications in key industry verticals. Certain alternative spectrum management approaches have been put forward as options with these industrial applications in mind, such as spectrum sharing and set-asides.[13] Chinese policymakers should, before making any decisions, carefully reflect on how these potential alternatives may impact the success of 5G services and applications.

3.3.1. Sharing agreements

Sharing agreements can be allowed by regulatory regimes on a voluntary basis or may be mandated by the regulator in order to fulfil certain policy goals. In voluntary spectrum sharing agreements, operators may choose to share spectrum with both traditional and non-typical providers of telecommunications services. This option can enable certain super-fast 5G services and promote the efficient use of spectrum. In this way, operators maintain certainty over access to licensed spectrum, with the spectrum being used in an efficient manner to best promote the provision of widespread, quality 5G services and applications, including for non-traditional spectrum users like industry verticals. In mandatory spectrum sharing arrangements, MNOs are obligated to share spectrum with certain users under defined criteria. Unlike voluntary agreements, operators' access to licensed spectrum is diminished, due to the obligation to share spectrum with other users. This decrease in spectrum may limit MNOs' ability to provide quality service, thereby reducing the value that operators place on the spectrum. Therefore, policymakers in China should consider mandatory spectrum sharing with care given these potential drawbacks.

8. Government of China (2019), "5G + Industrial Internet" is approaching."
9. 3GPP (2019), "Release 15," https://www.3gpp.org/release-15.
10. ITU (2012), "ITU towards IMT for 2020 and beyond," https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx.
11. GSA (2020), "5G Device Ecosystem," https://gsacom.com/paper/5g-device-ecosystem-report-february-2020/.
12. Government of China (2019), "5G + Industrial Internet" is approaching," Originally published by the Economic Daily, https://translate.googleusercontent.com/translate_c?depth=1&rurl=translate.google.com&sl=zh-CN&sp=nmt4&tl=en&u=http://www.gov.cn/xinwen/2019-12/02/content_5457468.htm&xid=17259,15700023,15700043,15700186,15700190,15700256,15700259,15700262,15700265,15700271&usg=ALkJrhiXjGTda8p7G44cnlpOFD7QqDexxg (December 12, 2019, at www.gov.cn).
13. MIIT (2019), "China 5G Development and Policy," https://static1.squarespace.com/static/5bf2b77d75f9eefcd937cb5c/t/5d1a20eb11a9570001f95d65/1561993455970/5.+Julin+LIU.pdf. See also, for instance, the MIIT's recent press release, MIIT (2020), "Information Technology Development Department participates in 2020 Zhongguancun Industrial Internet Innovation Solutions Summit," http://www.miit.gov.cn/n1146290/n1146402/n1146440/c7622172/content.html.

3.3.2. Spectrum set-asides

Spectrum set-asides for use in specific industry cases or verticals also have been discussed in China. Notably, some industry verticals may advocate for access to dedicated spectrum to support advanced broadband capabilities in their private networks, including direct access to spectrum bands that are crucial to 4G and 5G networks. Striking the right balance to support 5G industrial applications is a key priority for the government, as evidenced by its "5G + Industrial Internet Plan."[14] It will be of vital importance that China finds the appropriate balance to ensure that MNOs have reliable access to mmWave spectrum while at the same time providing connectivity to enable the wide array of 5G industrial applications across industry verticals.

There are several risks in setting spectrum aside exclusively for non-traditional operators in in mmWave spectrum in China. These include:

- Spectrum is at risk of being underused;
- Fair assignment and use of mmWave spectrum may be undermined, as additional users require further coordination and may compete with MNOs under significantly different conditions and obligations; and
- The ability of national MNOs to reach the full range of 5G capabilities and use cases may be limited as less mmWave spectrum is available.

A major component of 5G networks is the ability of mobile operators to support the needs of a wide variety of industry verticals in China, including setting specific network parameters for particular groups of 5G applications. This provides an alternative approach to spectrum set-asides in mmWave bands in the country. In order to realise the goals of the government's "5G + Industrial Internet" plan, sufficient mmWave spectrum should be made available to mobile operators in China to deploy 5G networks. In addition to the technical capabilities of 5G technology, MNOs have the expertise to support industrial applications and maintain the networks for continuous provision of service, fulfilling the quality and deployment requirements of different industry verticals.[15]

5G enables new approaches to traffic management for particular uses (e.g., network slicing) to deliver the appropriate quality of service to different users or groups -- mission-critical, public safety, passive sensors, consumer broadband -- positioning mobile operators to best support the different needs of specific vertical users. As such, given the expected importance of 5G to China, it is vital that policymakers ensure mobile operators' access to mmWave spectrum to facilitate these use cases.

14. Government of China (2019), "5G + Industrial Internet" is approaching," Originally published by the Economic Daily, https://translate.googleusercontent.com/translate_c?depth=1&rurl=translate.google.com&sl=zh-CN&sp=nmt4&tl=en&u=http://www.gov.cn/xinwen/2019-12/02/content_5457468.htm&xid=17259,15700023,15700043,15700186,15700190,15700256,15700259,15700262,15700265,15700271&usg=ALkJrhiXjGTda8p7G44cnlpOFD7QqDexxg (December 12, 2019, at www.gov.cn).

15. Government of China (2019), "5G + Industrial Internet" is approaching."

4. Case studies

As described above, low, mid, and high-band spectrum will each play key roles in 5G networks. Low and mid-band spectrum (below 6 GHz) has wide coverage capability, but more existing users, meaning that large contiguous blocks of spectrum may not be available, reducing their total capacity. High bands, such as mmWave bands, have smaller coverage areas for each cell, but relatively few existing users, meaning there are more contiguous blocks of spectrum available and correspondingly additional capacity.[16] Therefore, the low bands will be important for providing wide coverage and continuous service, while mmWave spectrum will be key to bringing additional capacity and higher throughput to 5G networks. These added capacity and high throughput capabilities will support the scope of data-intensive and low-latency applications foreseen under 5G. It should be noted that while in some cases these applications could be supported by lower bands, the potential of mmWave really comes into play when considering the massive scale of connected devices that should be supported in a specific area, such as those described in the two use cases below.

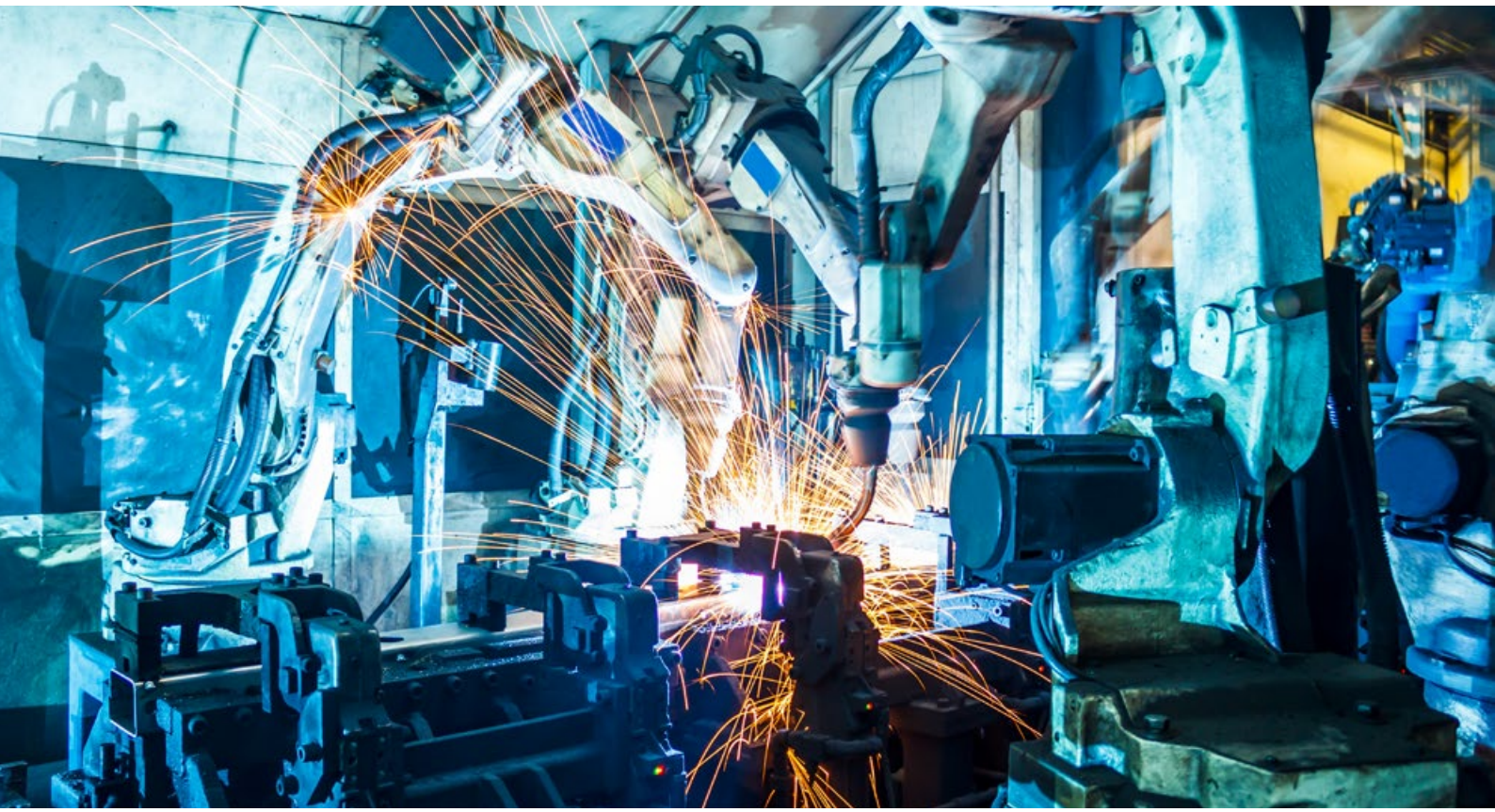
mmWave can greatly boost the capacity and latency capabilities of 5G networks. First, widespread implementation of industrial automation, especially processes requiring a high degree of precision, will benefit from added capacity due to the bandwidth availability of mmWave spectrum.[17] The significant amounts of data that each autonomous robot is expected to generate or receive, as well as the density of these robots in confined areas, should also be supported by mmWave 5G. Second, in a transportation setting, the criticality of maintaining a high-speed connection is doubly important given the potential negative safety concerns if the connection is lost or delayed. As the number of connected vehicles is expected to grow, especially in dense urban areas, the volume of data transmitted will be vast, making mmWave even more important. Predictions on data volume for connected vehicles project massive increases compared to average mobile data use: Intel forecasted that autonomous vehicles would transmit 4 terabytes of data per day, while ITS Automotive predicted the average car could transmit up to 30 terabytes per day.[18]

Furthermore, the volume of mobile data is expected to continue to grow and place more demands on mobile networks. As the volume of data being transmitted continues to increase, the added capacity of mmWave bands will become even more necessary for networks. Therefore, adding mmWave bands in 5G can help to make networks become more "future-proof" to handle increased mobile data traffic in years to come.

16. See also Rangan, S., et. al. (2014), " Millimeter-Wave cellular wireless networks: Potentials and Challenges, " https://ieeexplore.ieee.org/document/6732923.

17. Semiari, O. et. al. (2018), "Integrated Millimeter Wave and Sub-6 GHz Wireless Networks: A roadmap for Ultra-Reliable Low-Latency Communications," https://www.researchgate.net/profile/Mehdi_Bennis/publication/323141860_Integrated_Millimeter_Wave_and_Sub-6_GHz_Wireless_Networks_A_Roadmap_for_Ultra-Reliable_Low-Latency_Communications/links/5a8d25e5a6fdcc786eb06393/Integrated-Millimeter-Wave-and-Sub-6-GHz-Wireless-Networks-A-Roadmap-for-Ultra-Reliable-Low-Latency-Communications.pdf.

18. Intel (2016), "Data is the new oil in the future of automated driving," https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/#gs.w50hec. HIS Automotive forecasts as referenced in SAS (2015), "The Connected Vehicle: Big Data, Big Opportunities," https://www.sas.com/content/dam/SAS/en_us/doc/whitepaper1/connected-vehicle-107832.pdf.



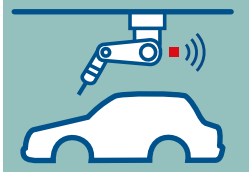
4.1. Industry 4.0 – Manufacturing

As shown in Section 2, China's manufacturing sector is the largest contributor to mmWave spectrum's estimated impact on GDP, accounting for 62% of the total. The potential of mmWave 5G technology presents numerous opportunities to promote Industry 4.0 and to drive efficiency and productivity. The government has similarly seen the potential of 5G industrial applications with the goal to foster innovation in industrial 5G applications and develop at least 20 typical industrial application scenarios under its "5G + Industrial Internet" plan.[19]

China is already a world leader in the deployment of smart manufacturing, with a growing share of companies reporting higher profits due to the use of connected devices in manufacturing processes.[20] Furthermore, the country leads in demand for industrial robots, making up 20% of the global market in 2017.[21] China is well-positioned to capitalise on smart manufacturing, as its comparatively newer factories – relative to manufacturing centres in Europe and the Americas – are ripe for the deployment and retrofitting of industrial robotic processes.[22] mmWave spectrum can support the necessary network conditions for manufacturers to realise the full potential of interconnected devices and autonomous processes by providing high-capacity, low-latency wireless connectivity. Numerous mmWave 5G applications can help realise the potential of 5G for Industry 4.0, including remote control systems, industrial robotics, remote monitoring and quality control, and autonomous factory transport (see Table 1).

19. Government of China (2019), "5G + Industrial Internet" is approaching," Originally published by the Economic Daily, https://translate.googleusercontent.com/translate_c?depth=1&rurl=translate.google.com&sl=zh-CN&sp=nmt4&tl=en&u=http://www.gov.cn/xinwen/2019-12/02/content_5457468.htm&xid=17259,15700023,15700043,15700186,15700190,15700256,15700259,15700262,15700265,15700271&usg=ALkJrhiXjGTda8p7G44cnlpOFD7QqDexxg (December 12, 2019, at www.gov.cn).
20. Deloitte (2018), "China's smart manufacturing: a steady push for the long term," https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/energy-resources/deloitte-cn-eri-2018-china-smart-manufacturing-report-en-190403.pdf.
21. Deloitte (2018), "China's smart manufacturing: a steady push for the long term," https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/energy-resources/deloitte-cn-eri-2018-china-smart-manufacturing-report-en-190403.pdf.
22. Deloitte (2018).

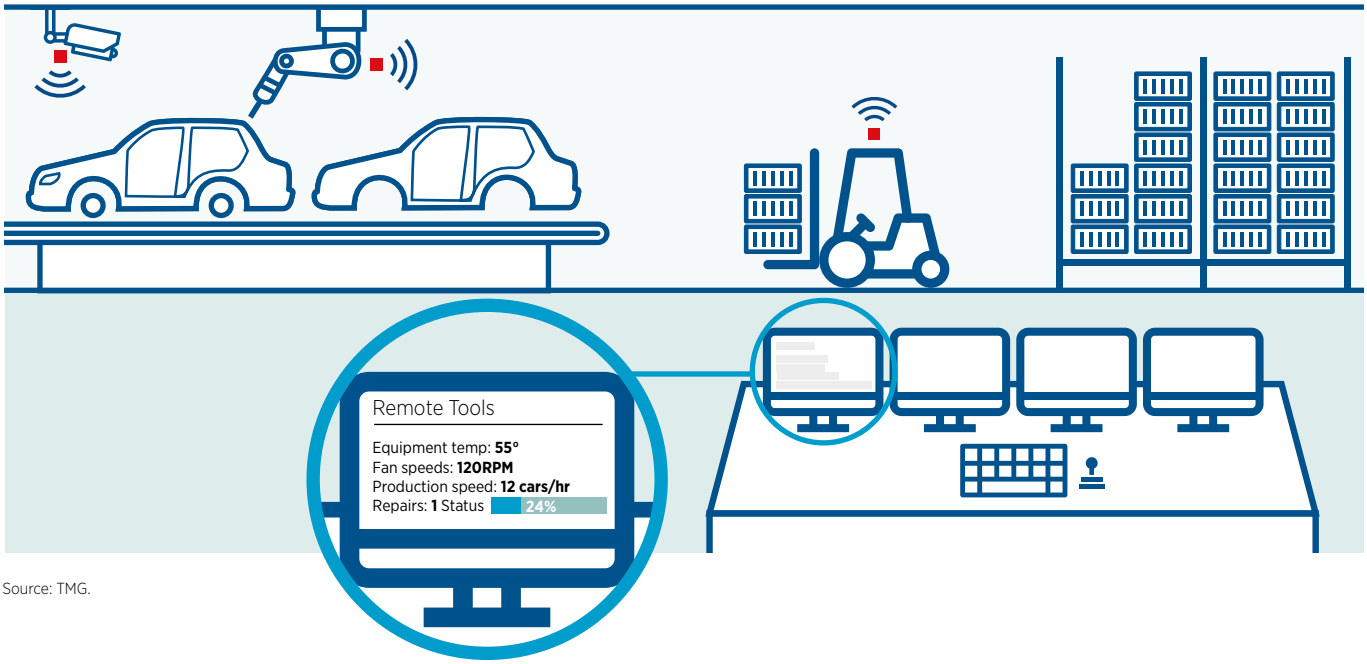
TABLE 1. mmWAVE 5G INDUSTRIAL APPLICATIONS

Remote-control systems 	Remote object monitoring and manipulation can be implemented to increase efficiency and improve safety in smart factories. Industrial processes that involve volatile chemicals or temperature-sensitive materials can be made safer by the remote operation of factory equipment. Efficiency can also be improved by allowing one remote operator to stop, slow, or accelerate any of the connected machines based on real-time feedback to a central control station.
Industrial robots 	Industrial robotics allow each piece of machinery within a smart factory to respond nearly instantly to requests and directions, enabling a rapid response in production to meet real-time shifts in demand. This also makes the customisation of manufactured products possible at a scale previously unattainable. Communication between these connected devices could also increase efficiency.
Remote monitoring and quality control 	Real-time data collection and analysis, especially data-intensive processes such as high-speed imaging and virtual and augmented reality applications, can improve production and provide on-the-job training by enabling: • Employees to see real-time data on the factory floor and compare the images of defective machinery with those in working order; • New employees to be trained through virtual simulations; • Advisor/specialists to assist remotely when not on the factory floor or to put in place an automated process for workers to troubleshoot independently of the specialist.
Autonomous factory transport 	Similar to a broader transport setting, autonomous vehicles in a factory setting (e.g., carts, cranes, etc.) can communicate with a central control or monitoring centre, as well as other machines, devices, objects, and broader infrastructure within the factory.

Taken together, the potential applications outlined in the table above would result in a large amount of data being transmitted by the vast number of connected devices expected in an Industry 4.0 setting. The sheer volume of data, along with the critical nature of some of the applications, such as remote-control systems and autonomous factory transport, as well as the amount of data to support advanced augmented reality (AR)/virtual reality (VR) applications and high-speed imaging, will require the reliable, high-capacity, low-latency connectivity of mmWave spectrum. The comparatively small coverage area of the factory floor, compared to a wider setting, is also well-suited to the natural propagation characteristics of mmWave band spectrum.

In addition, each of these applications can be implemented to work together in a factory setting, as depicted in Figure 4. For example, connected robots can be integrated into existing factory lines to collect and analyse data in real-time as well as monitor and flag maintenance issues or problems. Autonomous factory transport with self-guiding machinery can move components efficiently around the factory floor by communicating with the surrounding infrastructure and central command. Remote analysis, as well as remote operation of devices, can allow a remote operator to troubleshoot and make decisions in real-time based on factory conditions.

FIGURE 4. POSSIBLE mmWAVE 5G APPLICATIONS IN AN INDUSTRY 4.0 SCENARIO



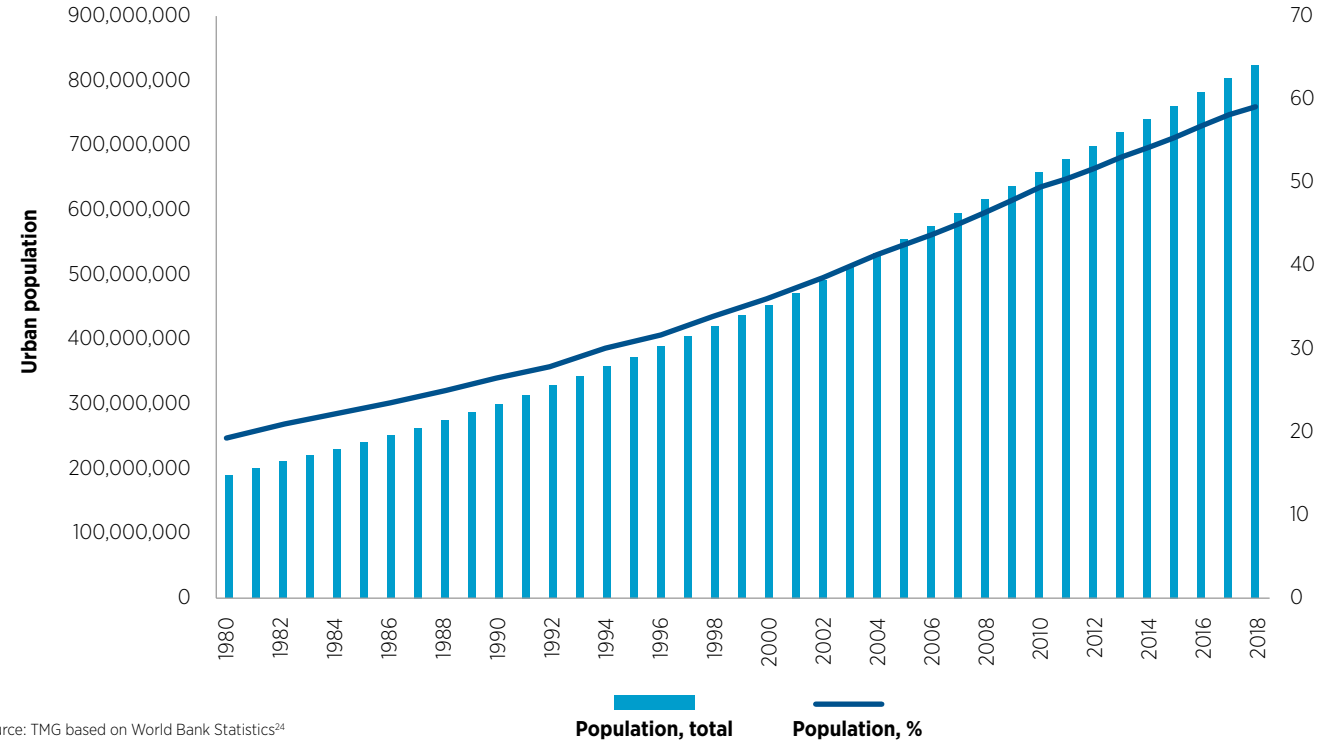
Source: TMG.

mmWave 5G will be necessary to provide the high capacity and low latencies necessary to support these industrial use cases. China stands to greatly benefit from implementing industrial applications such as remote-control systems, industrial robotics, remote analysis and monitoring, and autonomous factory transport, to improve safety and efficiency on the factory floor.

4.2. Connected transport

Transportation in China is an especially important sector, given the need for transport infrastructure to move its vast population every day. As China's urban population has grown, so too has the burden placed upon its transportation systems. The urban population has grown steadily since the 1980s, reaching close to 60% of China's 1.4 billion total inhabitants (see Figure 5).[23] This rapid urbanisation has caused cities to grow quickly, often resulting in urban sprawl. As these cities expanded, many challenges emerged due to outdated city planning and infrastructure that was developed before the influx from rural areas.

FIGURE 5. GROWTH IN CHINA'S URBAN POPULATION, TOTAL AND PERCENTAGE, 1980-2018



Source: TMG based on World Bank Statistics[24]

The growth in urban populations has been coupled with an increase in private vehicle ownership. China's National Bureau of Statistics reports that the number of privately-owned vehicles in the country grew by an average of 20% annually between 2006 and 2015, but the number of urban roads only grew at a rate of 3.5% each year.[25] This imbalance suggests that the current road infrastructure is inadequate to handle the growing demands placed upon it by an increasing number of urban travellers. Given the sheer numbers of urban dwellers, this applies not only to road infrastructure for private drivers but also to other means of public transportation options. An overburdened transport system is coupled with other effects, such as rising housing costs in city centres. This, in turn, causes many employees to move beyond city limits for more affordable housing options, resulting in longer commutes and more dependence on reliable transportation infrastructure to get to work.[26]

23. World Bank Group (2018), "Urban population (% of total population): China" and "Population, total: China," latest data reported in 2018, https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=CN and https://data.worldbank.org/indicator/SP.POP.TOTL?locations=CN.
24. World Bank Group (2018), "Urban population (% of total population): China" and "Urban Population: China," latest data reported in 2018, https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=CN and https://data.worldbank.org/indicator/SP.URB.TOTL?locations=CN.
25. Du, L. et. al. (2018), "Sustainable strategies for transportation development in emerging cities in China: A simulation approach," https://doi.org/10.3390/su10030844.
26. BBC (2017), "The grueling, six-hour commute of Beijing's workers," https://www.bbc.com/worklife/article/20170221-the-gruelling-six-hour-commute-of-beijings-workers.

These circumstances have made the proper management of transportation and traffic management a key issue in China. Some of the challenges posed by urbanisation and an overburdened transportation system can be addressed by mmWave 5G solutions, which have been noted by the government as a potential application of 5G.[27] mmWave spectrum can support a connected transport environment through its increased capacity and low-latency broadband, which are especially critical in transportation applications where a delay or loss of connection can result in severe consequences.

A comprehensive vehicle-to-everything (V2X) ecosystem can deliver various improvements in safety and traffic management, including:

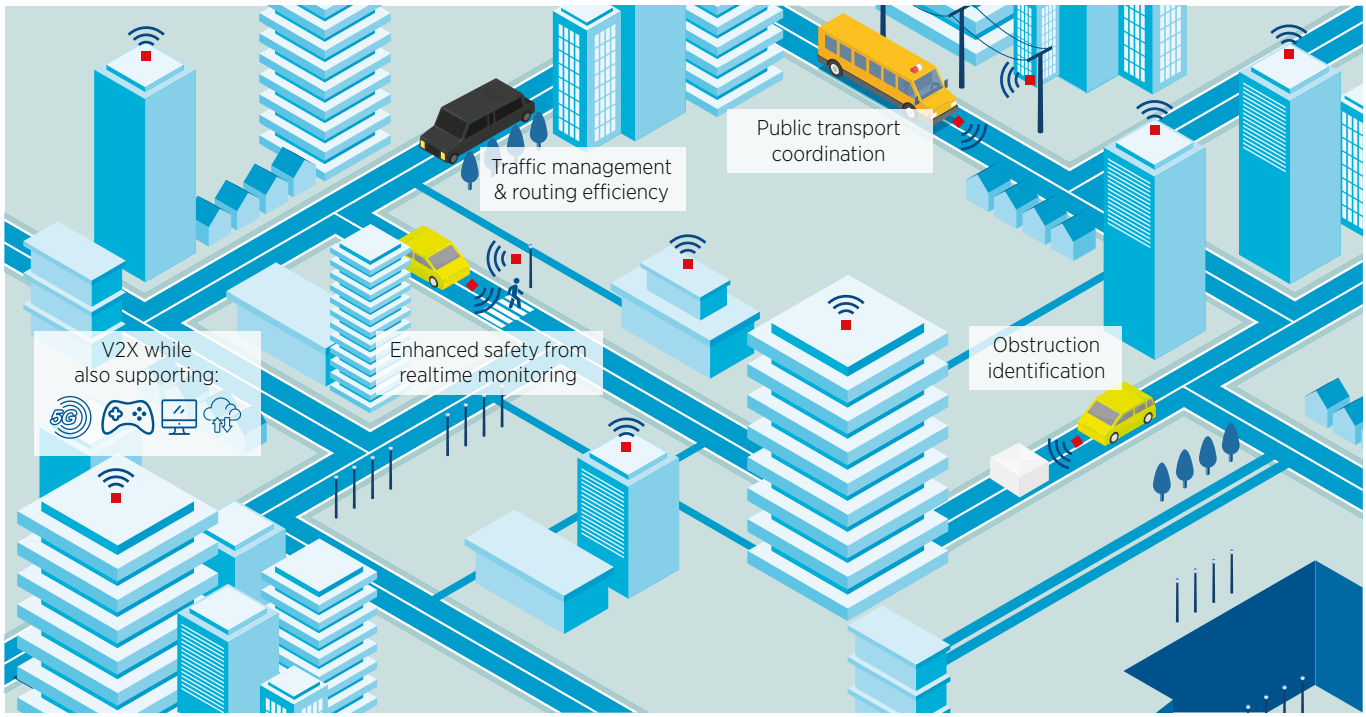
- Vehicle-to-vehicle (V2V) - safety through vehicle platooning;
- Vehicle-to-Infrastructure (V2I) or Vehicle-to-Roadside (V2R) - advance collision or obstruction alerts;
- Vehicle-to-Pedestrian (V2P) - alerts of pedestrian crossing or the presence of cyclists and their distance from the vehicle; and
- Vehicle-to-Network (V2N) communication - better adherence to traffic rules and adaptive driving in cases of automated or assisted driving.

V2X environments can also facilitate better traffic management. Platooning, enabled by V2V communication, not only improves safety by making adaptive recalibrations to speed and direction in reference to other vehicles in the close proximity, but can also serve to smooth the flow of traffic by driving at a faster pace than would be possible under normal driving conditions with a human pilot (see Figure 6). This is feasible largely through the continuous data sharing between the vehicles in the platoon.

Additionally, another possible use of V2X applications is to implement intelligent transport systems (ITS) to reduce congestion in urban areas. Connected sensors and cameras in infrastructure and vehicles can send high-quality, detailed, real-time information on traffic flows, accidents, and congestion to traffic management centres. In turn, these centres can analyse the data to reroute or re-signal traffic infrastructure and relay that information instantly to connected vehicles (see Figure 6). Over time, the data can be analysed and assessed to make effective and impactful urban transport planning decisions to manage traffic patterns, as well as to maintain detailed and up-to-date navigation maps for drivers. ITS could also help to implement public policies, such as prioritising public transportation options over other modes of transportation when such an effort is in line with the government's goals.

27. Government of China (2019), "China vigorously promotes the construction of 5G and other information technology services for smart cities," originally published by the Xinhua News Agency, November 29, 2019, posted on www.gov.cn, https://translate.googleusercontent.com/translate_c?depth=1&rurl=translate.google.com&sl=zh-CN&sp=nmt4&tl=en&u=http://www.gov.cn/xinwen/2019-11/29/content_5456970.htm&xid=17259,15700023,15700043,15700186,15700190,15700256,15700259,15700262,15700265,15700271&usg=ALkJrhjlv1OF4qww2yRozObuX16MbANsSQ.

FIGURE 6. POTENTIAL MMWAVE 5G APPLICATIONS IN A CONNECTED TRANSPORT ENVIRONMENT



Source: TMG.

Finally, while not directly related to better traffic management, mmWave 5G networks can also enable immersive in-vehicle entertainment and high-speed broadband. These possible applications have been discussed for their potential in advertising and entertainment.

Applications enabled by mmWave 5G present many possibilities for China to lessen the burden on its urban transportation infrastructure through V2X ecosystems and the use of intelligent transport systems.

5. Conclusion

The expected socio-economic impact of allocating mmWave spectrum for 5G networks in China is significant. As demonstrated in the two case studies presented, the implementation of mmWave 5G applications in an Industry 4.0 scenario and a connected transport scenario promise a number of benefits. mmWave spectrum, especially in the 24.25-27.5 GHz and 37-43.5 GHz bands, has the contiguous spectrum necessary to provide additional capacity to support a number of data-intensive 5G applications. For China to stay focused on the future for its citizens and continue to experience economic growth, spectrum should be assigned as soon as possible and in sufficiently large blocks to ensure operators are able to deliver on the high-speed, high-capacity, and low-latency capabilities of 5G. Furthermore, these bands should follow regional precedent and be assigned with no initial charges for spectrum fees.

Delivering the 5G vision for China and its citizens requires mobile operators to invest in extensive network deployments. To ensure certainty for this investment, network operators should have the opportunity to obtain exclusive licensed access to spectrum on a long-term basis. Sharing can be a practical tool to use spectrum more efficiently, especially in cases where band refarming is infeasible. Similarly, spectrum set-asides may be considered, although China should look at this option very carefully so as not to jeopardise network investment or limit MNOs' access to licensed spectrum. However, where other enterprises need access to spectrum, for instance for private networks within a vertical, voluntary subleasing agreements between mobile network operators and the leasing company should be encouraged and allowed to ensure all parties are able to capitalise on the potential of mmWave 5G.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