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5G Digital World —Built on Chips

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Contents

1. Abstract

2020 is certainly an extraordinary year. Governments around the world have been implementing policies to promote 5G technologies and applications, which has plunged operators worldwide into even fiercer competition in large-scale commercial rollout of 5G and trials in vertical industries. The COVID-19 pandemic has not only retarded the rapid development of 5G networks and the interconnected world but has also exerted a profound impact on the usage habits of global consumers. Meanwhile, this also allows us to take time to look into the future of 5G and the interconnected world from a new perspective.

In the entire software and hardware ecology and application scenarios, chips are essential to almost all hardware and vertical applications, in which they perform all the key tasks of data collection, flow, storage and processing.

The use of chips enables data aggregation, flow, distribution and processing among cloud, channel, edge and terminal, bringing about a digital world which is comprised of cellular network, communication chips, mobile terminals, CPE, wearables and software platforms etc. Such a system allows technologies to co-exist and co-develop, while facilitating the realization of greater commercial value through deep integration and iteration of cutting-edge technologies.

On the basis of the industry characteristics, 5G and AI are brought together to work out personal intelligent solutions for the consumer electronics industry, provide support for the industrial system of industrial electronics, make the business world more intelligent, and explore and innovate in the new area of ubiquitous networking.

Due to the presence of technical barriers and market factors, there are only few chip manufacturers worldwide that are able to provide full-scenario communication chip solutions. It is high time for chip enterprises to seize the opportunities of the market and the times to keep improving the chip product ecosystem and deepening the understanding of application scenarios, provide competitive solutions in relation to advantageous markets and application scenarios, and pave the way for the dawning of a total digital and interconnected world.

2. An Interconnected World Driven by IoT and Communication

2.1. Communication Technologies Extend the Scale of the Interconnected World

The first generation of the PC-based internet was realized by connecting computers through fixed-line communication. With the emergence of smartphones, the mobile internet powered by the mobile communication technology connects not only computers, but also mobile phones and the people behind them. The emerging Internet of Things (**IoT**) is a complex network connecting people with people, things with things, and people with things, via a variety of communication modes.

In the past decade, the term “Internet of Things” (IoT) emerged and became the trend of mainstream technology in the industrial and consumer market. These technologies of communication among “physical objects” have brought significant convenience. The development of digital and communication technology laid a solid foundation for the expansion of the IoT coverage. People started to conceive a future with the IoT even when the technology could not yet support extensive digitization and network connection. As the interconnection technologies, such as cellular network, wireless LAN, and short distance communication, gradually upgraded and became mature, multiple ecosystems of different scales were formed around various industries and consumers. With the development of communication technologies, especially the upgrading of telecommunication technology based on cellular networks, smartphones and other interconnection products for consumer market have become the key point for people to access the internet. Moreover, the IoT has entered another era of explosive growth in scale, with a growth rate of connections three times that of the mobile internet.

Although the 2G/3G and 4G technologies played an important role in the early development of the IoT, their standards were not designed for the IoT. These technologies are not sufficient to deal with the rapidly increasing number of devices and higher bandwidth requirements, and lack the edge of differentiation to compete with other short distance communication technologies such as Bluetooth, Wi-Fi, and Zigbee. Therefore, an IoT consisting of more than tens of billions of devices is not a target market for the conventional cellular communication technology, which also limits the growth of the number of devices connected to the IoT. The current landscape of the IoT is expected to change with the emergence of 5G technology, which may support more flexible applications to satisfy the interconnection requirements in consumer, industrial, commercial and other diversified scenarios

with better performance. The 5G technology is expected to lead to a new wave of popularization of IoT devices.

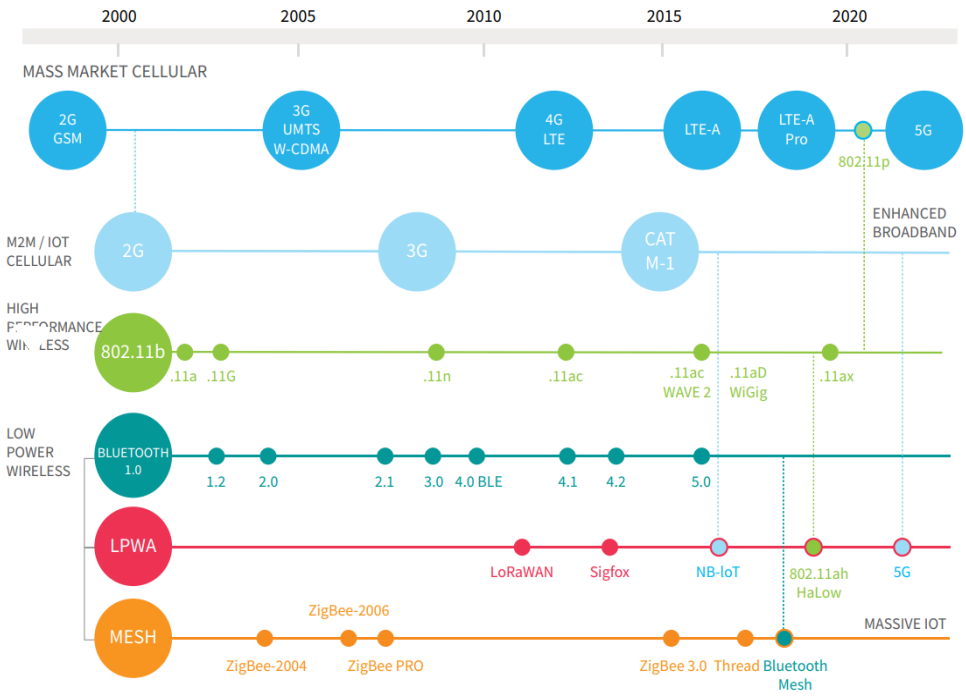

Figure 1 Development Route of the IoT Communication Technology

2.2. IoT and Chips Lay the Foundation of the Interconnected World

In the architecture of the Internet of Everything, whether it is for consumer electronics or industrial applications, the life cycle of data can be generally summarized as a closed loop consisting of collection, processing, refining and feedback. To a certain extent, the key foundation of this closed loop is mainly three types of chips, i.e., sensor chips, processor chips and communication chips. The collaboration in the data flow process supports the foundation of the ecosystem of personal and consumer entertainment, interconnected working/homes, and industrial IoT and Internet of Vehicles. Every time there is a technological upgrade of these key chips, it will drive the rapid upgrade of corresponding applications, or lead to a new form of applications. Meanwhile, the society has high requirements for future applications, which also drive and provide direction for the development of the chip industry. Chips and applications, as the bottom and top layers of the entire IoT, have formed a long-term complimentary and mutually promoting relationship.

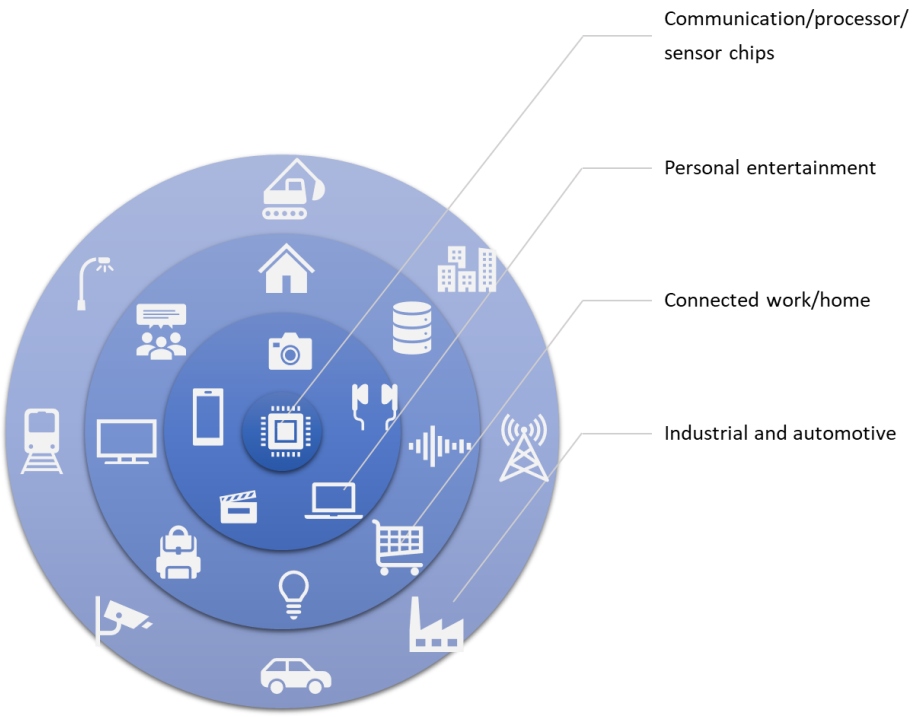

Figure 2 IoT Architecture with Three Types of Chips as Core Hardware

Sensor chips are at the front end of the IoT. They directly perceive the physical world and convert the perception into digital signals. The sensing precision and speed are key performance indicators. With the increasing requirements for sensed objects and granularity, sensor chips also evolve from processing simple signals to sensing and generating massive data flow within milliseconds and are playing an increasingly important role in the IoT. In particular, in those applications involving

multidimensional sensing and massive data, such as image sensors and 3D structured light chips of urban high-definition video devices, the performance of the sensor chips substantially determines the operating quality of the entire system.

Processor chips undoubtedly play a core role in the IoT devices. They are responsible for processing all data from human-machine interface, sensors, local software and cloud, and can quickly discover information from the data according to algorithms. Processor chips include system-on-chip (SoC) that integrates multiple chips and modules, MPUs that are good at parallel processing, FPGAs with flexible applications, DSPs for processing digital signals, ADC/CDA chips for analog-to-digital/digital-to-analog conversion, power-managing PMICs, audio chips, etc. All interconnected devices are equipped with such processor chips to achieve their core functions. Higher degree of integration, more and powerful functions, and lower power consumption will become the universal trend of the development of processor chips for the future interconnected world.

Communication chips are key components for devices to communicate with the outside world. They are responsible for the efficient transmission, encoding and decoding of data between nodes in the IoT. Standards of communication chips include not only 2/3/4/5G cellular networks, but also Bluetooth, Wi-Fi, NB-IoT and ultra-long-distance GNSS navigation system. To achieve complex data transmission, a device is usually equipped with more than one type of communication chips, and supports multiple network standards. The performance of communication chips in terms of data processing and transmission is becoming more and more sophisticated with the growth of data transmission by applications. In the 5G era, communication chips have been required to handle Gbps-level bandwidth data streams, and in some mission-critical applications, communicate data with millisecond-level latency. The core performance (standard, power consumption, bandwidth, etc.) of these communication chips has become the key indicators that drive the development of devices in terms of interconnection properties, but sometimes it also limits the development of more advanced interconnection applications.

3. 5G+AI Establish the Foundation of Application Scenarios

AI technology was put into practice earlier than 5G technology. Although, generally speaking, AI technology is still at the early stage of "weak" intelligence, the four major skills pursued by AI, i.e., **perception, learning, abstraction and reasoning**, have been realized to a certain extent. However, with more demanding application requirements, the volume of data to be processed and the depth and breadth of information discovery to be achieved by AI technology have been greatly increased. Therefore, the form of AI tends to simulate the structure and working pattern of human brain, and AI may conduct self-training and reasoning more autonomously through machine learning algorithms. In the next phase, AI technology is expected to develop to the general multi-modal AI, which can perform extremely complex and granular data analysis, continue to conduct structured data training, and generate highly flexible solutions for different applications.

Therefore, 5G and AI technologies converge on terminal devices, and their intersection is the requirements of massive data: 5G technology provides wider data channels for terminals, while AI acceleration engine technology provides more optimized tools for processing the massive data and further optimizes the interaction between users and devices. Due to the stringent requirements of mobile terminals for power consumption and integration, IC companies with technical advantages use more advanced manufacturing processes to integrate 5G baseband, GPU, CPU and NPU onto a single SOC chip, and use AI accelerator cores to optimize the calculation of massive parallel data. In this way, the training and inference can be completed in the course of processing large volume of low-precision data, and the performance of devices can be maximized in AI applications. Local applications conduct computation and optimization using local AI computing power, while applications involving more voluminous data, more intensive interaction and higher computing power requirements are processed in collaboration with the cloud via the 5G high speed communication channels, so as to avoid waste of computing and storage capacity.

3.1. 5G+AI in Smartphones

Smartphones have become the most important interface connecting consumers with the smart interconnected world. They are also the most powerful hand-held computing centers. Each of the smartphones we own today has more powerful computing capacity than NASA's supercomputer used for the Apollo moon landing in 1969. The next question is: What can we do with smartphones besides moon landing?

The strong computing power and AI algorithms of mobile processors bring extensive possibilities. From the security perspective, AI enables the built-in 2D or 3D camera to identify the owner's face or expression details and recognize the user within tens of milliseconds for unlocking the smartphone or authorizing a payment. AI algorithms need frequent self-training and updating, so that they can remember and learn from each scan and update the facial features which may change with age, makeup or weather, so as to prevent misrecognition caused by masks, photos or similar methods. By now, this technology has achieved payment-class security, and has been widely used for online payments.

Another pain point of smartphone user is photography. Especially with the development of online social activities, people are eager to post the photos recording every pleasant moment of their life. The quality of a photo usually depends on the parameters and sensors of the camera lens and the photography skills, such as adjustment of aperture, shutter, white balance and composition, which restrict ordinary users from producing satisfactory photos. The AI-powered photography technology looks like but is far more than fool-proof photography. It can greatly improve photography quality. Driven by AI algorithms, the photography module can identify hundreds of different scenarios, calculate the lighting condition, and then automatically adjust parameters and choose the suitable camera mode. In addition, it can accurately identify human faces in complex background and lighting conditions, and beautify faces based on facial feature analysis. Therefore, even an amateur can use an AI-enabled smartphone to take very professional photos.

For VR/AR applications, the future development of the extended reality (XR) technology largely depends on the user experience and rich and attractive applications. In respect of user experience, VR technology needs to provide a display area that is perceptually enlarged hundreds of times for each eye. Therefore, the display with ultra-high pixel density becomes the key to improving user experience, which brings huge challenges in terms of both graphic processing capacity and network bandwidth. As most interactive AR/VR scenarios will use both local and cloud computing capacity, the bandwidth advantage of 5G network has become one of the keys to addressing the pain point.

For AR applications, the first task is to accurately identify the real scenario, which practically sets even higher technical requirements for more powerful and real-time graphic processing and network response speed. Currently, real-time processing for these applications incurs substantial costs. More market competition will bring huge growth opportunities, and thereby reduce costs for ordinary consumers. Local IC design and infrastructure companies will also play an important role in the market.

In addition, AI technology has escalated voice-related applications from basic communication to a more intelligent level. When a user is on a call in a noisy environment, the voice processing algorithm can accurately identify the features of speech and background noise, and remove the noise to improve voice quality. It can also accurately identify the voice scenarios, and choose the suitable voice algorithm matching the scenarios. Furthermore, advanced voice AI algorithms can understand semantics of speech, even under the conditions of dialect or incorrect grammar, support continuous dialogue scenarios based on the understanding of semantics, and lead the development of human-machine interface in the direction of acoustic interaction. Real-time AI translation function will be a matter of course when semantic understanding is achieved.

These advanced complex algorithms have brought huge demand for computing and storage capacity. Nowadays, many smartphones are equipped with special AI chips to take over the tasks of CPU, so that graphic processing can be completed at a faster speed with lower power consumption. When the local computing capacity is insufficient to handle more demanding tasks, the cloud AI platform can take over and complete the processing, identification or optimization tasks remotely. As the resolution of smartphone photos continues to increase, this mode is expected to become more popular in the near future, with the emergence of 5G technology. The entire transmission + processing can be completed within an extremely short period of time, making the user experience virtually the same as the complete local processing. Local processing and cloud AI processing are likely to coexist and collaborate with each other for a long time to improve the system-level work efficiency and optimize the use of network data flow and computing capacity to the greatest extent.

3.2. 5G + AI in Other Scenarios

In addition to numerous applications for smartphones, AI-enabled chips, in combination with the 5G network, can bring significant changes to more vertical industries such as industrial, service and urban governance sectors. Although the entire AI market is growing rapidly at a two-digit growth rate, the AI technical resources and experts in the smart home, industrial and other similar fields are rather limited in number, and further improvements are required from the following perspectives:

- **Scale:** Instant access to thousands of machines and sensors to perform complex and sophisticated data analysis
- **Performance:** Sufficient power consumption to rapidly address differentiated AI workload
- **Quality:** Structured data and system training through accurate and reliable model and appropriate input data
- **Customization:** Flexible and adjustable solutions and scalable platforms for different a-pplications to ensure profitability of business cases

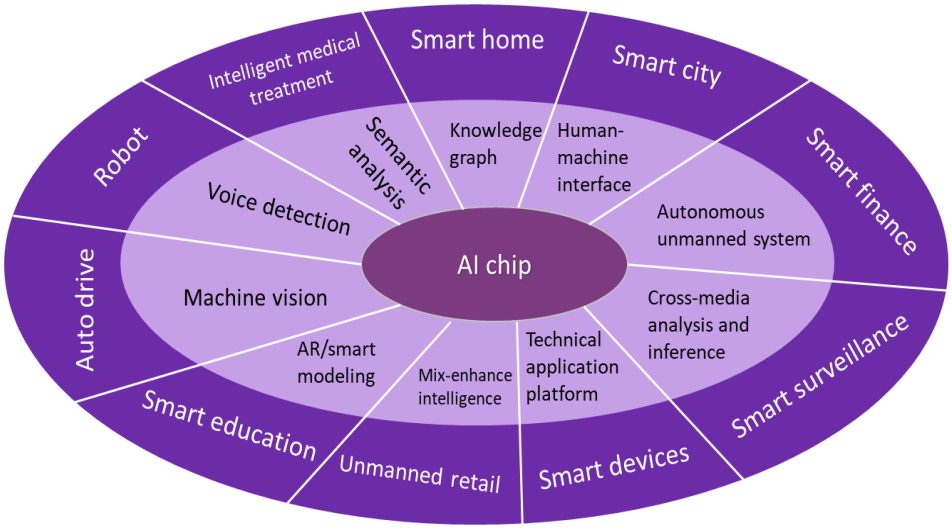

Figure 3 Practical Application of AI + Chips in Multiple Scenarios

Take the chip-mounted applications that implement AI functions on the terminal side as an example. After satisfying the requirements above to a certain extent, smart monitoring devices can locally perform certain graphic analysis and processing tasks and extract key information to reduce the pressure on the bandwidth and computing capacity on the backend and cloud; power grid patrol inspection robots can automatically identify various potential safety issues related to the power grid; smart home appliances can automatically adjust temperature, humidity, shading, lighting and electrical appliances based on the perception of the users' daily life patterns. Applications with extremely stringent latency requirements usually do not have high requirements for bandwidth. Therefore, the use of AI on the edge side can effectively reduce the bandwidth pressure on the 5G network to improve communication efficiency, and in some private and sensitive applications, AI functions enabled on the edge and terminal sides can maximize the local processing of sensitive information to address the security concerns with the upload of sensitive information to cloud. Therefore, though the cloud has the strongest computing power, the AI functions enabled on the edge and terminal sides can still optimize the efficiency of the entire structure and enhance the flexible deployment of computing power.

4. Discover the New Commercial Value of IoT

4.1. 5G Network Upgrades and Catalyzes a New Generation of Application Scenarios

Like the “Age of Exploration” hundreds of years ago, the discovery of a new world will attract and encourage people to think out of the box, explore and connect the world and create wealth. As the society enters a new interconnected world driven by 5G, new thoughts, new applications and new commercial value will inevitably arise.

In the 2G and 3G eras, consumers were impressed by the value created by the mobile network, even though it only supported transmission of texts and images. Since the commencement of the 4G era, the 4G technology has opened up the gate to a new world for online content providers and users, creating great commercial value. Applications based on videos and games are ubiquitous in people’s life. A popular short-form video app may have more than 400 million daily active users, and the number of daily active users of various leading online video streaming platforms may reach around 200 million. These applications have become the important driver of the Chinese and even global internet economy, and helped the video and gaming platforms achieve the incredible success in just a few years. The entertainment function of fixed devices such as televisions and desktop PCs has rapidly declined, and the mobile devices have become an important form of access to entertainment contents.

Similarly, 5G will bring even deeper changes to the information age. Although it takes a reach of imagination to predict the future of 5G applications, it is undoubted that the upcoming revolution will be as astonishing as the changes brought by 4G technology a few years ago. It is even more necessary to change the inherent pattern of thinking, and recognize how 5G will change the way of interaction between users and the digital world, and affect the landscape of vertical industries.

The most evident feature of the 5G network that distinguishes it from 4G is its network management technology, i.e., “network slicing”, which enables operators to create multiple virtual networks based on the physical layers of a single 5G network to cope with three different types of scenarios respectively requiring enhanced mobile broadband (eMBB), massive machine type communication

(mMTC) and ultra-reliable low latency communication (URLLC). Whether it is for AR/VR, online ultra-HD video, and wide coverage smart city projects, which require high bandwidth, or industrial machines/mobility, which requires low latency, the 5G network can provide the flexibility that is most essential for these applications, at a cost that is adjustable according to specific requirements; and the slices can be reused as needed. The following chart briefly illustrates the featured basic applications of three types of scenario slices:

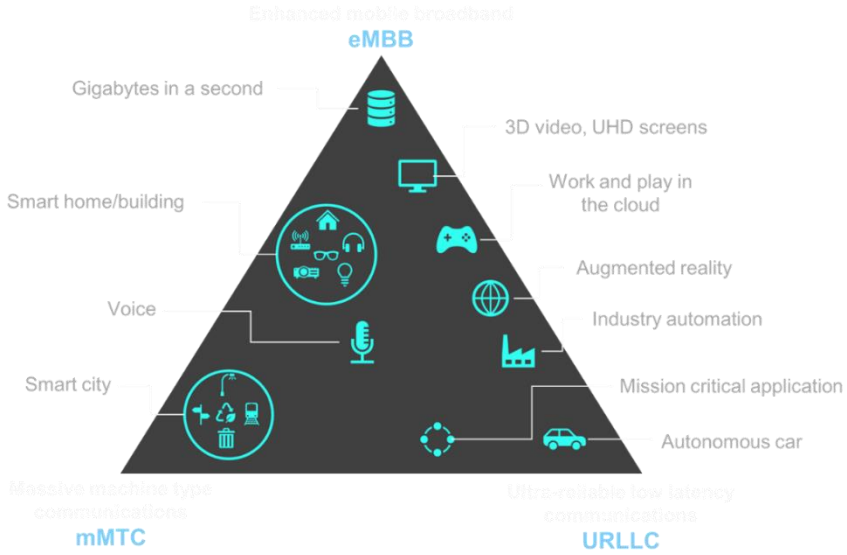

Figure 4 Typical Applications of 5G in Three Major Scenarios

The chart below shows the predicted timeline of evolution (i.e. initial deployment - popularization - heavy use) for certain typical applications in the three major scenarios. In addition to the widely used applications such as mobile phones, more consumer multimedia applications and industrial or commercial applications, in

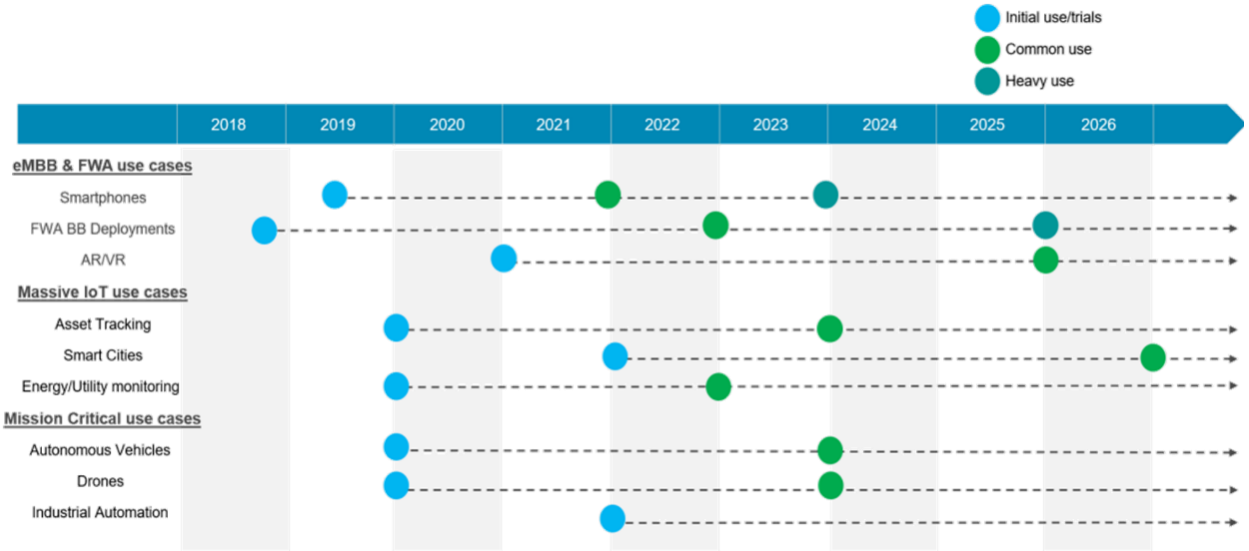

Figure 5 Timeline of Evolution for Certain Typical Applications in the Three Major Scenarios

particular consumer multimedia, industrial/corporate/municipal and automotive applications, will be deployed from 2020, and become mature around 2023.

- Consumer applications mainly include the applications on 5G mobile phones, and fixed wireless broadband and AR/VR applications. These applications are mainly related to enhanced mobile broadband (eMBB) scenarios. The 5G technology is expected to be first deployed in this type of applications.
- Industrial/corporate/municipal applications have wide coverage. Scenarios involving massive machine coverage mainly include asset management, smart city, and remote monitoring of energy and municipal facilities, and ultra-reliable low latency application scenarios mainly include applications of industrial robots and drones.
- In the field of the Internet of Vehicles and Autonomous driving technology driving technology, with the development of applicable laws and regulations, and the implementation of the Internet of Vehicle standards and the 5G ultra-reliable and low latency standards, the autonomous driving technology will become mature, bringing great potential to the autonomous driving market.

From a mid to long term perspective, with further development of slicing technology and business models, more interesting applications will be added to these three fields, such as remote construction machinery, remote real-time surgery, virtual travel experience, autonomous driving buses. It is evident from the chart below that unmanned, remote and large-scale applications will become the keywords of the future IoT:

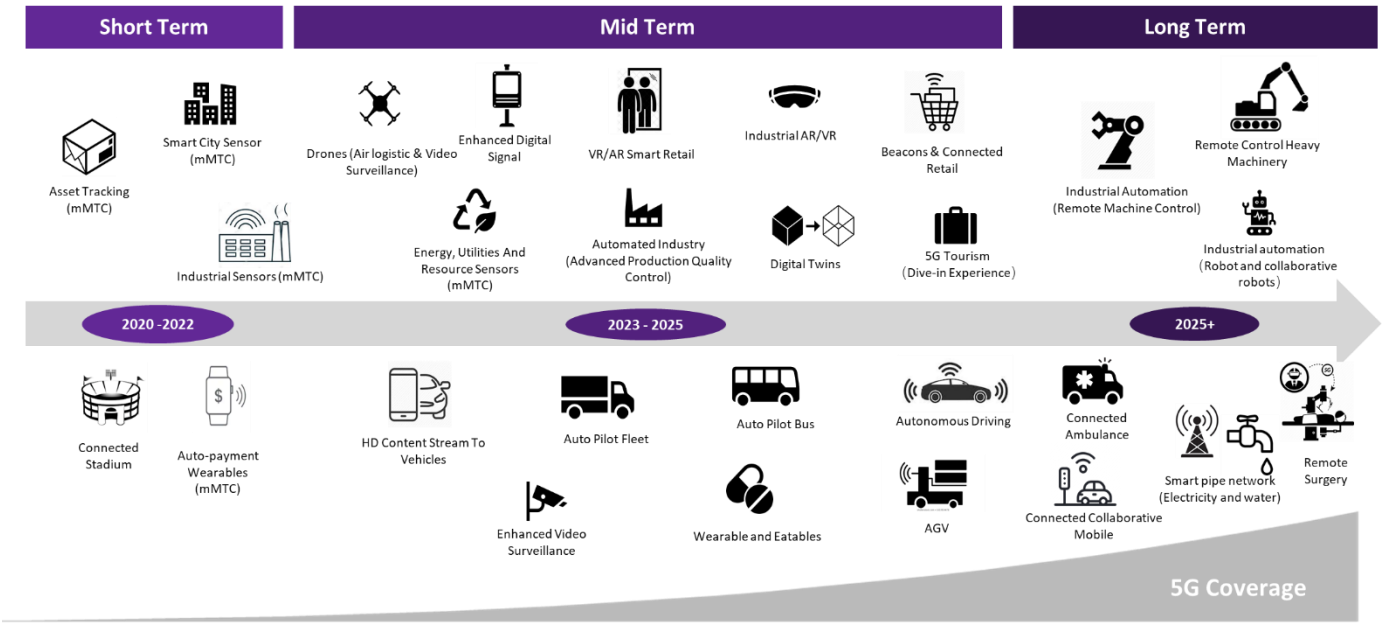

Figure 6 Unmanned, Remote and Large-Scale Applications will become the Key to the Future IoT World

4.2. Consumer Market Application Scenarios

The consumer electronic market includes not only gaming, video and television applications, but also many 2B industrial scenarios, such as sports, healthcare, remote monitoring, education and retail, particularly multimedia-related applications. According to the estimates of Omdia, the total size of the entire consumer multimedia market will increase from USD649 billion in 2018 to over USD900 billion in 2023. The consumer and B2B entertainment and media income will have a dominant position, representing 90% of the total market value. This type of applications calls for stringent requirements on broad bandwidth and low latency for the mobile network. Bandwidth and latency have become the bottleneck and pain point restricting the further development of emerging applications such as online cloud games, VR/AR, ultra HD streaming video, and real-time remote medical services. The enhanced mobile broadband (eMBB) experience offered by the 5G network will remove this bottleneck, while creating unprecedented experience and new business models in this so-far largest 5G application market.

Whether it is video games, HD live streaming or online shopping, the key to the upgrade of consumer applications lies with the form of human-machine interaction, i.e., touch (e.g., press of buttons), acoustic (e.g., voice recognition), and visual (e.g., graphic UI, gestures, and facial expression recognition) communication and interaction between humans and machines. More advanced human-machine interaction in the future will involve exchange of massive information flow, and use of AI technology to conduct deep understanding and analysis of user behaviors or thoughts. For example, eyeball tracking, gesture tracking, brain waves or micro-expression reading can help users free their hands from controlling terminal devices. These advanced interactions require not only powerful hardware, but also complex algorithms, including real-time sensing/image processing capability and complex parallel computing capability.

Low latency below 20ms is the key to removing the bottleneck restricting the development of applications with high real-time operation requirements, such as multiplayer online cloud games and VR/AR immersive experience. 4G or similar mobile communication technologies (50-100ms) are unable to meet such requirements to achieve the seamless multiplayer collaboration for cloud games. The user experience of VR/AR applications tend to be seriously affected by video delays, and 5-10ms latency is required to ensure smooth experience of highly interactive high-end VR applications. With the ultra-low latency, the high-definition high-frequency video streaming powered by broad bandwidth will further improve user experience. In some graphic rendering applications requiring light-weight office or extreme computing power, the reduction of communication latency makes cloud computers practical. It can not only address the challenges of centralized IT security management for large companies, but also break the computing power bottleneck of personal terminals for image and video processing, rendering and modeling applications which require high computing power, and complete tasks with the help of cloud computing power. In such scenarios, in front of a user is just a terminal equipped with an I/O interface, a network card, and a display, which serves as an

interface between the user and the cloud. The reduction of latency can provide an interactive experience as smooth as local interaction, and greatly improve the configuration flexibility and security.

After gradually solving these pain points with broad bandwidth and low latency, the 5G network will create development opportunities for the remote, high definition, real-time and multi-user mobile applications, and lead to changes of the business models. Taking sport or entertainment live streaming as an example, the combination of eMBB-based ultra-HD signal transmission channels and HD terminal devices triggers new revenue models. An event sponsor obtains access to dedicated network channels from an operator, and sells tickets (in the form of network access) to remote audience so that the audience can have an audio-visual experience on their mobile phones, televisions, VR goggles and other 5G HD terminals, which is similar to the onsite experience. In addition, the live broadcaster can provide full-dimensional live streaming of the event, using drones and other shooting methods, so that offsite audience can freely choose points of view or playback, which offers an experience that is not available to onsite audience. In this business model, consumers will have an unprecedented entertainment experience, and operators, event sponsors and terminal manufacturers will have a new source of profits. The realization of this scenario is expected to generate billions of dollars of additional revenue every year for the sports industry alone.

4.3. Industrial/Corporate/Municipal Application Scenarios

Cellular communication modules have been widely used in the industrial/corporate/municipal markets since the 2G era. As the government promotes the transformation of the 2G/3G network, the 4G modules have rapidly replaced the 2G/3G modules in many business scenarios. However, the 4G modules cannot fully meet certain demanding requirements for high reliability, low latency, and integrated networks. The conventional 3G/4G public network channels cannot provide differentiated communication services required for industrial purpose, unless the expensive optical fiber or LTE private networks are used. This restricts the further popularization of the technology.

In this June, Omdia conducted a survey among over 100 industrial companies around the world in respect of their specific expectation of the 5G technology for the industrial market. Their feedbacks can be considered as the most basic point of interest of the industrial and corporate market in the 5G technology. The most popular feedbacks ranking the first and second places (and with a substantial lead) among these feedbacks expect the 5G network to improve the flexibility and innovation of businesses respectively. It reflects that the corporate users' opinion on 5G has gone beyond the conventional IoT itself, i.e., 5G is not just an auxiliary means of production and operation, but a key tool for industrial transformation and upgrade.

In the municipal, petroleum, energy, electricity and process manufacturing industries, various communication modules have been widely installed on all kinds

of equipment, devices and instruments. These industrial IoT application scenarios usually consist of tens of thousands of connected devices at the same time. These communication modules upload the information collected by various sensors to remote data centers and cloud servers. Driven by Industry 4.0 and other similar technical concepts and the manufacturing industry upgrade policy, the market is about to see a rapid growth of the number of devices equipped with communication modules. Omdia estimates that the shipment of connected devices will be around 6 billion by 2024, and rapidly increase to 35 billion by 2030, 50% of which will come from the Asia-Pacific market. According to a survey, dozens of operators around the world that have deployed 5G will have their future profitability focused on corporate, municipal and industrial IoT scenarios, which further demonstrates their confidence in this market.

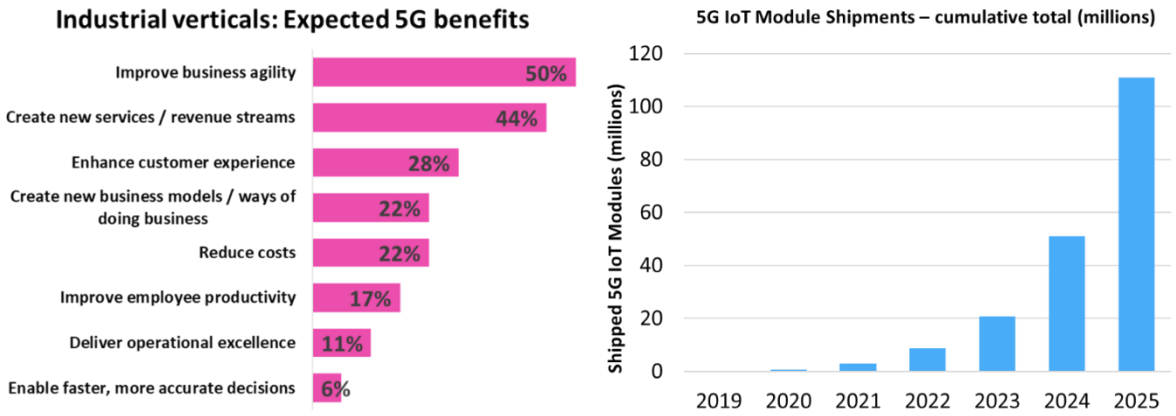

Figure 7 Forecast of the Expectation of 5G in the Industrial Field and the Global Shipment of 5G IoT Modules

The massive high-density access and reliability of the massive machine type communication (mMTC) of the 5G network plays a vital role in these scenarios. And with the improved low power consumption, the availability on authorized and unauthorized frequency bands, and the more flexible network coverage, the 5G technology will significantly reduce the costs of the large IoT so as to promote the extensive application of the large-scale IoT in more vertical industries. As it officially becomes the 5G standard, the NB IoT, with the characteristics of “large connectivity, wide coverage, low power consumption, and high security”, will gain the support of the mainstream operators, equipment manufacturers and chip manufacturers around the world, and the technical research, development and industrialization will be accelerated in many industrial/corporate/municipal vertical industries.

Electronic manufacturing, automated power distribution, automobile manufacturing and other industrial scenarios may also need real-time monitoring, upload and summary of massive production data and product data. Industrial robots and processing equipment may require communication with milli-second class latency, and the industrial IoT also requires ultra-high reliability and scalability of communication infrastructure. In the meantime, business owners also call for high network security, as well as controllable network deployment and operating costs. The uRLLC slice of the 5G network can meet the requirements for high precision and low latency in the automated control applications.

In addition to the mMTC and uRLLC scenarios, there are many mobile scenarios of the industrial IoT which require processing of high-definition images and videos, such as indoor and outdoor power line inspection, field construction work and oil and gas exploration based on AGVs, mobile robots and drones. In addition to performing 5G-assisted high precision indoor and outdoor positioning, mobile devices are also required to remotely upload HD images or videos to cloud for processing. This demands not only geographical mobility and coverage, but also higher power efficiency of communication modules, and most importantly, Gbps class bandwidth. This type of applications, which desires extremely high data throughput, will rely on the eMBB technology of the 5G network.

4.4. Automotive Application Scenarios

The most notable trending technologies in the automotive application scenarios are the Internet of Vehicles and the self-driving. Powered by a new generation of information and communication technology, and with a main architecture consisting of “cloud, channel, edge and terminal”, the Internet of Vehicles and autonomous driving establish a full-dimensional network connection, including in-vehicle connection, vehicle to vehicle connection, vehicle to road connection, vehicle to human connection and vehicle to service platform connection, which connects the transportation participating elements including “human, vehicles, roads and cloud”. They improve the level of automotive intelligence and autonomous driving capability and build a new form of business in the automotive and transportation service markets, thereby improving transportation efficiency and driver and passenger experience. To promote the innovation and application of self-driving, technology will also be conducive to building a smart automobile transportation scenario.

Form of Communication in the Internet of Vehicles

The inter-vehicle network realizes the communication between smart connected vehicles and the communication between smart connected vehicles and road infrastructure. Smart connected vehicles communicate with the Internet of Vehicles service platform, transmit vehicle data, and accept instructions from the service platform, through the 2G/3G/4G/5G cellular network, satellite communication, etc. The inter-vehicle network in the direct link mode uses LTE-V2X, IEEE 802.11p, radio frequency identification (RFID) and other technology to communicate information with nearby vehicles and road infrastructure.

A smart connected vehicle may communicate information with the mobile smart terminals of the users in the vehicle via Wi-Fi, Bluetooth or cellular mobile communication technology. The electronic components in a smart connected vehicle exchange information through onboard CAN bus, LIN bus, etc., and WIFI, RFID, Bluetooth, infrared, NFC and other wireless communication methods.

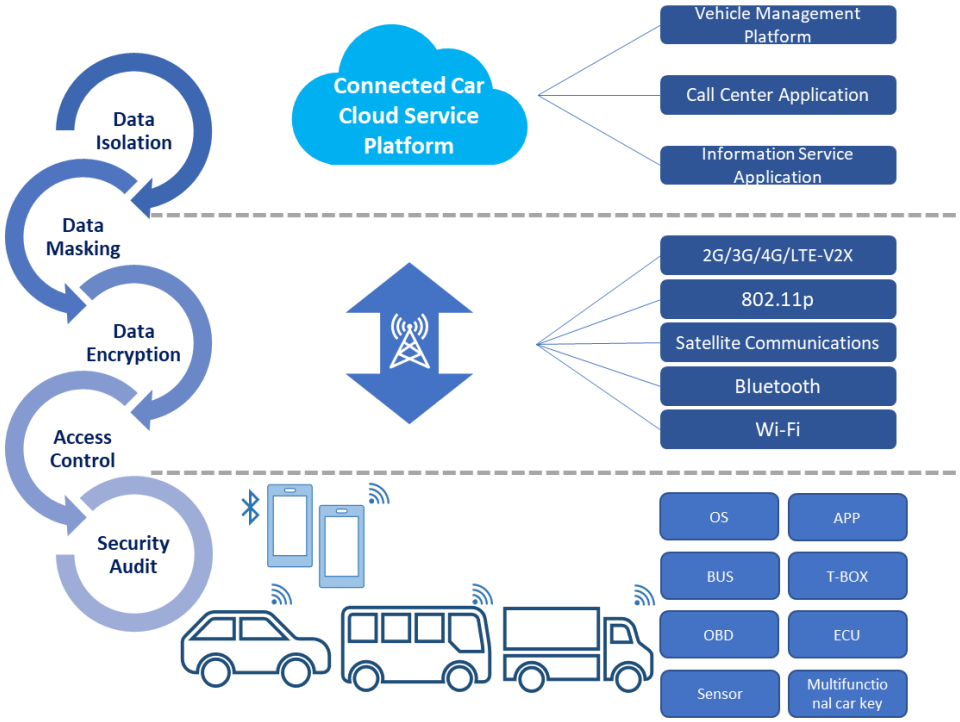

Figure 8 Cloud-based Internet of Vehicles Communication Technology and Applications

Promotion of the Development of the Internet of Vehicles and Autonomous Driving by 5G

With the commercialization of 5G and the readiness of autonomous driving technology, the Internet of Vehicles will undergo fundamental changes. Communication is the foundation of data transmission. The current 4G network with around 50ms latency is far from meeting the needs of self-driving, which requires a mobile communication network with low latency, high reliability, as well as the support of high-speed movement and large data capacity:

- **Low latency:** The end-to-end latency needs to be less than 5ms;
- **High reliability:** The packet error rate needs to be less than 0.001%, and the transmission reliability will be guaranteed even when traffic is congested, and limited spectrum resources are shared by a large number of nodes;
- **Support of high-speed movement:** The relative movement between vehicles may be as fast as 500km/h; and
- **Large data capacity:** A transmitted data packet can carry at least 1,600 bytes of information data.

The 5G network will bring more diverse Internet of Vehicles application scenarios, including high speed in-vehicle infotainment, ultra-HD video and voice calls, smart cockpits, mobile hotspots/offices/homes, dynamic digital map updates, self-driving, remote driving, remote monitoring and fleet formation.

Communication Modules Onboard a Smart Connected Vehicle

Whether it is the smart in-vehicle control screen, smart rearview mirror, smart cockpit or smart voice interaction module, they all need the basic support of the powerful in-vehicle network communication technology. T-BOX, OBD and OTA have gradually become the standard configuration for each vehicle, and the demand and application of onboard navigation, in-vehicle terminal dialogue, vehicle-to-vehicle communication and air upgrades have been increasing significantly in recent years, driving the continuous growth of the market demand

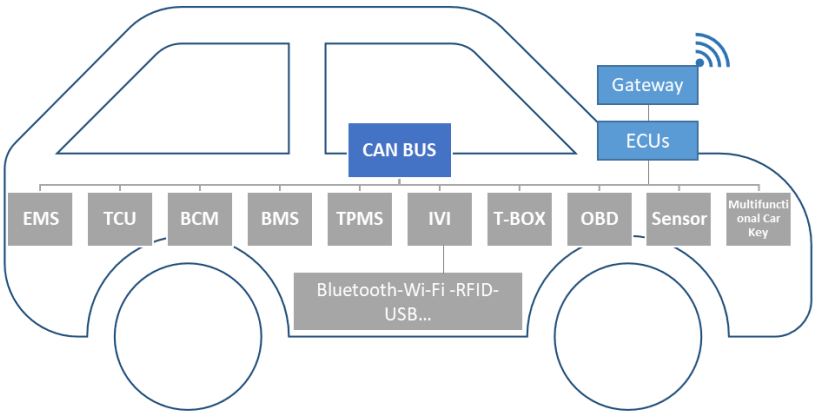

Figure 9 Communication Bus and Modules Inside a Connected Vehicle

for core onboard network data communication modules. The application markets of communication modules in the Internet of Vehicles mainly consist of the original equipment market and the aftermarket. Although the original equipment market is currently of larger size, the aftermarket of communication modules has huge potential, as the development of the smart Internet of Vehicles ecosystem and the refining of local regulations will increase the demand for upgrade, modification and monitoring of the existing smart vehicle systems, such as the remote monitoring of pollutant emission of heavy duty diesel engines, the upload of OBD monitoring and diagnostic data to the national or operation platform, and the OTA remote upgrade.

The On-Board Diagnostic (OBD) interface is the access point for an external device to communicate with the in-vehicle bus. Through the OBD interface, read and write instructions can be sent to the ECU by the Unified Diagnostic Services (UDS). T-BOX, as the gateway of information exchange between in-vehicle systems and external systems, can send remote control instructions to the cloud server, which in turn relays the vehicle owner's control instructions to the smart connected vehicle to achieve remote control and other functions of the vehicle, such as remotely turning on air-conditioning or vehicle preheating. The In-Vehicle Infotainment (IVI) system can provide real-time road conditions, navigation, infotainment, fault detection, assisted driving and other functions, offering a new passenger

experience. The Over-the-Air (OTA) function uses the cloud-based upgrade technology to acquire system upgrade packages for connected devices in an as-needed and easy-to-expand form, and complete system repair and optimization through OTA cloud upgrade. The remote upgrade function helps vehicle manufacturers quickly fix security vulnerabilities and software bugs and has become an indispensable function for the Internet of Vehicles. The ECUs are the brain of the systems onboard a vehicle, which controls the operation of these systems, such as engine, gearbox and lights. The ECUs are connected and communicate information with each other through the in-vehicle bus.

Communication Chips Onboard a Smart Connected Vehicle

Vehicles will have to rely on a large number of cellular communication modules based on the existing communication infrastructure to achieve various functions, whether the functions that are becoming popular rapidly, such as OTA, T-Box and OBD, or the macro Internet of Vehicles functions that are vigorously promoted by the governments and corporates, such as smart control, V2X communication, road condition detection, in-vehicle entertainment and assisted/self-driving.

Currently, the V2X communication technology for the Internet of Vehicles has two development routes, i.e., DSRC and LTE-V2X. DSRC was developed earlier and its technology is more mature, while its disadvantages lie with insufficient investment in road-side facilities and uncertainties in technological evolution. LTE-V2X has wider channels and better synchronization. As countries around the world accelerate the 5G deployment and commercialization, more and more major international automobile OEMs are switching from the conventional DSRC solution to LTE-V2X. Especially in China, the largest automobile market in the world, the government has decided to make LTE-V2X the mandatory requirement for C-ITS and related safety services. Domestic manufacturers in China have their own intellectual property rights in the core technologies of navigation chips. Some products have passed automotive-grade reliability certification, and are compatible with multi-modal navigation systems. Qualcomm is the leading player in the market of the communication chip technologies for the Internet of Vehicles. Chinese companies, such as Spreadtrum, Huawei and Datang, are also actively developing their presence in the automotive communication chip market by participating in setting the LTE-V2X standards.

3GPP, an international standard-setting organization, has announced the freezing of the R16 standard, marking the completion of the first evolution standard of 5G, which is also the first 5G-V2X standard (NR V2X standard). NR-V2X represented a smooth evolution from LTE-V2X to 5G-V2X. 3GPP introduced LTE V2X in R14, and then enhanced the function of LTE V2X in R15. In the 5G era, 3GPP R16 offered more advanced V2X services with the lower latency, higher reliability and higher capacity brought by 5G NR. The powerful 3GPP ecosystem and continuous and comprehensive cellular network coverage enable the mutual complementariness and compatibility of R16 NR V2X and LTE V2X. NR-V2X can directly tap into the existing cellular infrastructure to greatly reduce the costs of future deployment of autonomous driving and the Internet of Vehicles and make automobile smarter and safer. R16 defines and supports 25 advanced V2X application cases, which mainly cover four major areas:

- Fleet cooperative driving, where the leading vehicle shares information with the other vehicles in the fleet to allow the fleet to drive with a small distance between vehicles;
- Collaborative communication through extended sensors, where sensor data and real-time videos can be exchanged among vehicles, pedestrians, infrastructure units and V2X application servers to enhance UE's perception of the surrounding environment;
- Realization of full or semi-autonomous driving by communicating sensor data and driving intention;
- Remote driving, which enables remote control of vehicles in dangerous environment.

5. Chips in Vertical Industry Scenarios

5.1. 5G Chips in Consumer Application Scenarios

The data analysis in the foregoing chapter shows an evident future trend, i.e., in the era of full digitization of the physical world, online applications will experience unprecedented growth in both depth and breadth, and their user stickiness will be far higher than that of the weak digitization era. Driven by the booming demand for online applications, high-bandwidth communication networks such as 4G-LTE and 5G and mobile terminals with high computing and storage capacity have emerged to cater to the needs of consumers. Baseband chips are an essential component of these mobile terminals. They are responsible for connecting these terminals to the 5G network and processing massive data throughput, and therefore play a key role. As a type of digital chip for radio transmission and reception of data, a baseband chip mainly consists of five sub-modules, namely CPU, channel encoder, digital signal processor, modem and interface module. It mainly performs the information processing function of the communication terminal, including receiving, sending, encoding and decoding of signals with network devices. Plainly speaking, the baseband chip is the interface through which the other software and hardware inside the terminal communicate with external networks. It is designed to satisfy the needs of consumer market for mobile terminals with high computing capacity and broad bandwidth. In addition to 5G mobile phones, it can also be used in many other cellular network terminal devices of various classes and with various functions, including vehicle onboard devices, CPE, and wearable devices.

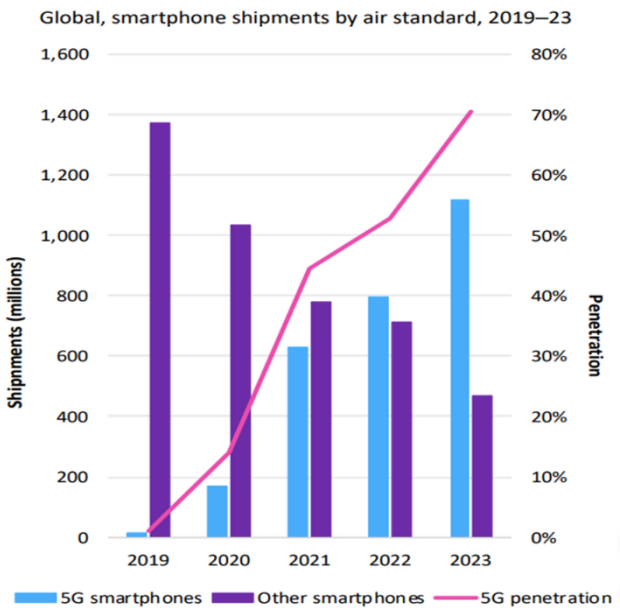

Figure 10 Global Shipment of Smartphones and 5G Penetration Rate

In the early days of 5G chips, as the application of baseband chips and SoC solutions was restricted by technical barriers, expensive price and limited

production capacity, they were only used in a few high-end mobile phones which were commercially available. With the efforts of more leading chip manufacturers, the mid-end 5G basebands/SoC solutions were soon launched, and significantly improved the market landscape and brought the larger mid-range mobile phone market into the 5G era. Against the background of global economic downturn and the impact of Covid-19 on the consumer electronic market, the 5G-powered devices at mid-range prices will undoubtedly boost the entire smartphone market. In Q1 2020, the total shipment of the Chinese smartphone market saw a year-on-year drop by 22% to 64 million units, while the shipment of 5G mobile phones was almost twice the shipment in Q4 2019. More 4G users are waiting for the price of 5G mobile phones and packages to fall to an acceptable level. As the price of 5G chips continues to go down, 5G mobile phones will be accepted by more users, creating even more demand for 5G devices. It is estimated that the annual shipment for the Chinese 5G mobile phone market will go up to 337 million units, with a penetration rate of over 87% by 2021, making China the largest shipper and destination market of 5G mobile phones in the world.

In addition to mobile phones, CPE is another type of important devices that are equipped with 5G chips. CPE is short for Customer Premise Equipment, which is an intermediary device between a 5G base station and a terminal. It converts 5G signals received from base stations to high-speed Wi-Fi signals covering indoor spaces, so that non-5G terminal devices such as Wi-Fi powered tablets, VR goggles and smart home appliances can also enjoy the advantages of 5G signals. As CPE can also provide stronger antenna gains with larger transmission power, it has far more powerful signal transmission and reception capability than hand-held devices such as mobile phones, and can therefore make up the shortage in 5G terminals or signals. In addition, high-power multi-access outdoor models may derive from 5G CPE to provide high speed network access for specific application scenarios and benefit more non-5G terminal applications. Omdia predicts that with the improvement of the 5G network infrastructure and the promotion by terminal manufacturers, 5G CPE will soon be widely used as wireless relay between home network and the internet, and gradually replace the role of the existing optical fiber fixed network. Furthermore, while connecting hundreds of devices and providing reliable high-speed network service with its own communication and computing capacity, CPE will also become the smart management hub of homes or offices, and the optimal human-machine interface between users and the entire smart equipment network, providing butler-style services for entertainment, video, office, social and other applications.

With the availability of more diverse 5G chip solutions, 5G-powered TV and other home multimedia terminals are another expected trend of evolution of the 5G technology. Having evolved from receiving analog signals to HD digital signals, TV is now mainly used for accessing internet contents. In the meantime, as the display panel technology continues to advance and the cost continues to fall, the size of TV is growing larger, 4K TV accelerates its penetration, and manufacturers also start to ship 8K panels. The interaction between TV and users tends to focus more on audio-visual experience, online applications and other similar aspects. The inherent advantages of 5G in ultra HD video data transmission match this trend. The 5G

technology can support applications such as TV-based indoor ultra HD video-on-demand applications, live streaming of sports and entertainment events, and low latency cloud-based games. This is a typical case where terminals and communication technology join forces for the first time. These applications will not only be attractive to TV manufacturers and 5G operators, but also create opportunities and challenges for online content platforms. Rich online contents and appropriate business models can eliminate the bottleneck that prevents the commercialization of 5G TV.

Tablets and laptops powered by cellular technology can no longer impress the market. Since the 3G era, the market has seen products equipped with embedded SIM cards, which enable the internet connection even when the users are travelling. However, tablets and laptops are intended to handle more demanding applications that are beyond the capability of mobile phones, such as large-screen HD video, digital hand painting and office applications. The real practical products did not exist until the commencement of the 4G era. This continued design feature shows that the more demanding requirements of mobile working or entertainment are still not satisfied even when Wi-Fi hotspots are ubiquitous. In the coming years when the 5G highway is being perfected, the online entertainment and working requirements of tablet and laptop users will quickly catch up and surpass the capability of the existing 4G network.

5.2. 5G Chips in Industrial Application Scenarios

One of the most evident features of Industry 4.0 is network connection. The most critical element of smart manufacturing projects is free flow of data. Therefore, communication and network connection are playing an increasingly important role in industrial application scenarios. Industrial network communication mainly consists of wired and wireless transmission. Currently, the main form of communication inside a factory workshop is wired transmission, including industrial PON and ethernet communication technology. As there are different standards of industrial field bus protocols, devices from different manufacturers cannot communicate with each other, and device status cannot be effectively monitored. Conventional industrial networks also have unstable latency, data islands, security risks and other issues. 4G, Wi-Fi, NB-IoT, LoRa, Zigbee and other industrial wireless communication methods are less used inside factory workshops, which means great potential opportunities for such applications. 2G, 3G and 4G communication modules are mainly used for communication between factories and in process manufacturing industries such oil and mining industries. Communication powered by 5G chips can achieve stable connection with low latency and high security, so that the device-device communication, human-device communication, workshop-workshop communication and factory-factory communication can be realized via the connection in a single network. It will help manufacturing companies fix the disorder of network connections used by their applications.

On the basis of network connection, the smart, flexible, service-oriented and high-end manufacturing is becoming a more evident trend in the development of manufacturing industry, and more and more 5G applications have emerged in the manufacturing industry.

Manufacturers have increasingly urgent needs for wireless networks with high performance and networking flexibility, and leading industrial companies hope that their application needs for device connection and remote interaction in an industrial environment can be satisfied. There are a large number of sensors in factories, which can report information status in a very short period of time through 5G or NB-IOT network, and there will be massive controllers, sensors and actuators with a high density that need to be connected through wireless network. Therefore, managers can have precise control and regulation of the in-factory environment.

In addition, 5G network can synchronize and send back the HD surveillance videos inside the factory to the control center, which videos can show the production details in all areas of the factory, so as to support the refined monitoring and management of the factory. The 5G technology will offer unprecedented transmission speed, massive human-machine connection and coverage scope, millisecond class end-to-end latency and nearly 100% communication reliability, which will promote the smart collaboration of humans, machines and objects, and lead to major changes in the manufacturing industry.

Video and image recognition are required in factory scenarios such as product fault detection, fine raw material identification and precision measurement. 5G network can guarantee real-time transmission of massive HD videos and images and improve the recognition speed and accuracy of the machine vision system. Based on the broad bandwidth and low latency of 5G, the combination of 5G+AI+machine visions enables the observation of micron-meter grade objects; comprehensive and traceable information can be acquired and easily integrated and retained, so as to change the entire quality inspection process.

Traditional industrial training is generally inefficient and ineffective due to the lack of professional education and training, the substantial costs of physical start-up of equipment, and the limitation on the venue and the number of attendees. With the broad bandwidth and low latency of 5G, cloud computing capacity can be utilized to achieve the operation, rendering, display and control of AR/VR applications, and efficiently convert AR/VR images and sound into audio and video streams, which will be transmitted to terminals in real time through the 5G network. 5G will meet the milli-second level latency requirements of remote multi-person collaborative design, virtual factory operation training and other industrial AR/VR applications with intensive interaction, and enhance the experience of user-user and user-environment interactions. 5G technology can also realize the real three-dimensional teaching, by bringing factories and production lines into classrooms and providing training and guidance through mobile classrooms.

In addition, production scenarios of large companies often involve cross-factory or cross-regional equipment maintenance and repair, and remote diagnostics. Conventional workshop operation and maintenance require tiresome travels of engineers and incur substantial labor and material costs. The 5G network will facilitate the real-time monitoring of the working conditions of production equipment throughout its life cycle, and realize cross-factory or cross-regional remote error diagnostics and repair, so that the maintenance and repair of production equipment are no longer limited by factory boundaries.

Case Study of Automated Warehouse and AGV in Manufacturing Workshops

Currently, the automated warehouses in manufacturing factories and the dispatch of AGVs in manufacturing workshops usually use WIFI communication, which involves issues such as vulnerability to interference, insufficient switching and coverage capability, difficulty in system deployment and high costs. The 4G network is no longer able to support the requirements of modern manufacturing factories, workshops and automated warehouses.

The broad bandwidth offered by 5G can facilitate parameter estimation, support high precision ranging and achieve precise positioning. The low latency of the 5G network can help acquire relevant data in a more rapid, intuitive and accurate manner in all logistics environments. The 5G network environment with low latency, broad bandwidth and extensive connection can support the connection of a larger number of devices and support the seamless switching between AGVs and AMRs in their movement, avoiding the disconnection of devices during the switching. The technical advantage of parallel broad bandwidth connection offered by 5G allows more AGVs to work collaboratively in the same work section at the same time; it can cover the whole room and connect all devices inside the room. On this basis, the cloud-based intelligent analysis, collaborative decision-making and other functions can improve the overall operating efficiency of the automated warehouses and workshops for the manufacturing industry, turn equipment into connected smart equipment, and eventually achieve the comprehensive collaboration of cloud, channel, edge and terminal:

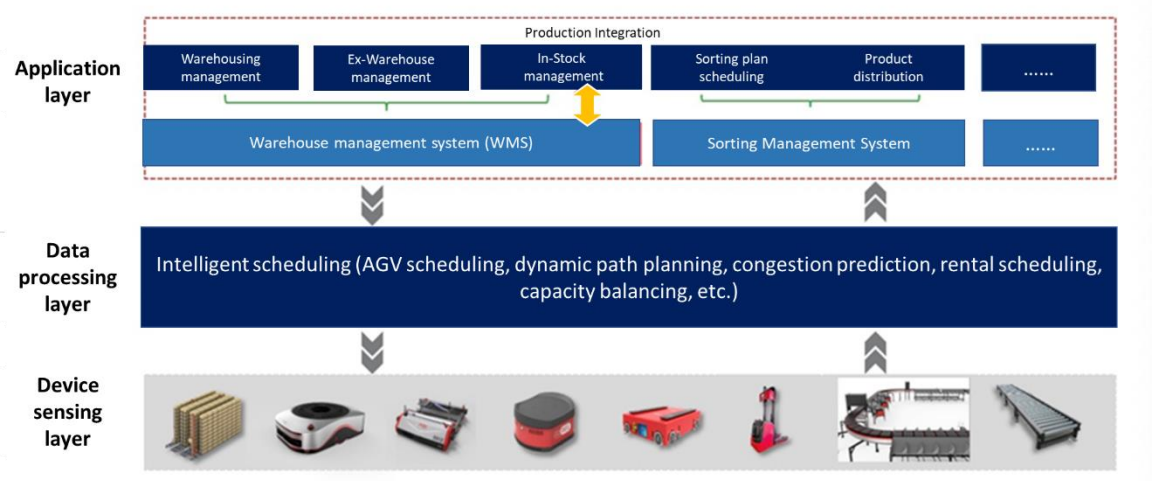

Figure 11 Different Business Levels of the Automated Warehouse Scenarios

The navigation, positioning, laser radar, visual image recognition and environment sensing functions of smart warehouse robots require complex computing capability. These requirements, together with the requirements of WCS, WMS and O&M platforms, are migrated to the 5G edge computing servers and cloud. The migration of computing units will reduce the costs of individual smart robots, and help expand and accelerate the application of smart robots. On the other hand, the modules that have higher real-time requirements, such as collection of sensor data, motion control/emergency obstacle avoidance, will physically remain in smart robots such as AGVs, AMRs and robotic arms to meet the safety and other relevant requirements.

The terminals in the automated warehouses and manufacturing workshops for the manufacturing industry take various forms. As a key component of the Internet of Everything, 5G chip modules play an essential role. Standardized 5G chip modules can be adapted and integrated into various terminals, such as AGVs, AMRs, forklifts and robotic arms, to quickly equip the terminals in the industry with 5G communication capability.

Case Study of Large Factories and Manufacturing Workshops in Industrial Parks

The previous section describes the application of 5G inside factories, workshops and automated warehouses. In large cross-regional companies and large manufacturing and logistics parks, private 5G networks can be used to achieve the collaboration of cloud, channel, edge and terminal. Complex computing functions can be migrated from the terminal-side to the edge-side so as to reduce the costs of terminal devices, including moving the smart computing which would have been performed by smart cameras locally to the edge-side, which will enable smart recognition of videos with ordinary cameras; moving the video analysis and AGV scale dispatching function of patrol inspection robots to the edge-side, so as to reduce complex computing performed on terminal devices and thereby reduce the costs of terminal devices. The final target is to achieve the data interaction among the security surveillance systems, 5G patrol inspection robots, vehicle guidance systems, and cloud-based AGVs in multiple factories of a large company and in a large industrial park.

Private 5G network, with the collaboration of cloud, channel, edge and terminal, can help these companies and industrial parks achieve:

- **Site management:** Automatic and intelligent recognition of arrival and departure of vehicles, through 5G+edge camera video playback and real-time intelligent recognition.
- **Personnel management:** Identify any “unauthorized persons” entering a specific area, based on the 5G IoT devices (HD cameras).
- **Vehicle management:** The entire process from the entry appointment, onsite operation to departure of a vehicle is managed online.
- **Production management:** The videos recording the entire process of an order or goods from the warehousing source to the end of distribution are spliced, using the 5G-powered input of ubiquitous video data.
- **Safety management:** 5G-enabled onsite cameras/patrol inspection robots will reduce the potential risks of aggravated safety, cost and quality loss that may be caused by an abnormal event.

The implementation of private 5G network and the collaboration of cloud, channel, edge and terminal will rely on 5G communication modules and 5G CPE. Basic modules consisting of main chips and RF frontend are mainly used in park robots, AGVs, industrial routers and other vertical terminals. Smart modules, which integrate microcontroller units (MCU) and AP with basic modules, can be used in park cameras, sorting/remote repair AR, product navigation VR and other industrial terminal applications. In addition, 5G CPE can be connected with surveillance cameras to achieve flexible and mobile deployment of CPE according to the actual site conditions, using the signal relay function of CPE.

5.3. 5G Chips in Automotive Application Scenarios

As 5G continues to be further implemented in the Internet of Vehicles application scenarios and the autonomous driving technology becomes mature, the Internet of Vehicles is developing from in-vehicle intelligence toward the direction of the “cloud-channel-edge-terminal” collaborative intelligence. The in-vehicle communication structure is evolving from ordinary CAN bus to high-speed ethernet, tapping into the features of real-time communication and broad bandwidth to meet the requirements for transmission of massive videos and images, and provide support for more Internet of Vehicles functions. The development of external V2X communication technology and road-side smart devices will help realize vehicle-vehicle, vehicle-road, and vehicle-human real-time communication.

As the T-Box technology becomes mature, the costs of originally installed T-Box for new models continue to drop, and T-Box has become a mainstream application scenario. Major automobile manufacturers actively promote positioning, navigation, driving safety, remote vehicle control, entertainment, after-sale services and related business, and their service offering is evolving from basic connected information services to safety alert, broad bandwidth business and assisted driving service. The future Internet of Vehicles will not be limited to simple scenarios such as the positioning and navigation services provided by T-box, but will support more Internet of Vehicles application scenarios to provide better experience for consumers. The autonomous driving function will see another wave of explosive development, including self-parking, automatic assisted lane changing, and autopilot navigation.

The demand for smart interactive infotainment system and smart driving will push forward the development of the smart cockpit market. Smart cockpit is becoming the third personal living space. In-vehicle control screens are evolving to large HD screens; ordinary dashboards and rearview mirrors are evolving to HD LCD dashboards and streaming media rearview mirrors. New display solutions, such as head-up display (HUD) and augmented reality display (AR-HUD), are also becoming more popular in the cockpit. The future smart interaction will use software to achieve functions such as smart interaction with vehicles and monitoring driver behaviors by integrating visual, audio and other perception data.

The value chain of hardware for the Internet of Vehicles has great potential. The upstream of the value chain mainly involves manufacturers of sensors, radars, communication chips, computing platforms, communication modules and various smart infrastructure hardware; the midstream mainly includes vehicle control or system integration service providers, TSP service providers, and smart cockpit solution providers; and the downstream mainly involves smart vehicle manufacturers, smart highways, testing/verification/operation/service, telecom operators and content service providers.

In the upstream of the value chain, with the rapid penetration of consumer electronic companies and semiconductor chip companies into the automotive electronics industry, the smart functions that used to be exclusively reserved for high-end models are becoming more and more commonly available in mid to low end models, and the cost of automotive electronics is accounting for an increasing percentage

in the total vehicle cost. The chip market has become an important arena for chip manufacturers.

Computing platforms need to further improve the computing power per watt, and use heterogeneous computing architecture such as CPU, GPU, FPGA and ASIC to provide stronger computing power support for sensing and decision-making algorithms. The control of new human-machine interaction increasingly requires flexible and shaped in-vehicle screens of larger size and with higher resolution, as well as various interaction methods such as gesture interaction, voice interaction and onboard HUD, which will promote the development of various driver chips. The control chips of actuators need to adopt a multi-redundancy design to ensure the safe and reliable switching between autonomous driving and manual driving modes. The Internet of Vehicles will promote the mass production and installation of V2X communication chips and onboard communication modules, as well as the construction and upgrade of road-side units, base stations and other infrastructure.

6. 5G Chip Competition Landscape in the IoT World

6.1. Competition and Role of Chip Manufacturers in the 5G Era

The development history of communication chips such as baseband chips is basically the development history of the entire mobile communication technology. In the 1980s, Motorola dominated the 1G chip market, and Qualcomm started to research and develop CDMA technology. In the 1990s and 2000s, many strong players including Nokia, Ericsson, Qualcomm, Alcatel, Siemens and Philips, rose in the baseband chip market, and fiercely competed for the digital 2G market. Due to the fierce competition during that period, many semiconductor companies went through division and reorganization, and Motorola, Texas Instruments, ADI, etc. successively abandoned the baseband chip market. The overall competition landscape turned from expansion to contraction, and European and US companies started to accumulate technologies for 4G chips. From the 2010s, Chinese companies started to appear in the 3G chip market, as Spreadtrum and HiSilicon marketed commercial baseband chips. In the meantime, due to the competition and merger and acquisition, almost all European chip manufacturers withdrew from the baseband market, and left the stage to the US companies which had strong technical capability and extremely high market shares, as well as the emerging companies such as HiSilicon, Unisoc, Samsung and MediaTek.

In the 4G era, the baseband chip market saw fundamental changes to the competition landscape, compared to the 1G or 2G era. Many traditional suppliers disappeared, and new suppliers entered the market through merger and consolidation of strength. Qualcomm shocked the industry by launching its five-mode and ten-band baseband, which soon occupied half of the baseband market. Despite the challenges from HiSilicon, Intel, MediaTek, Samsung, Unisoc and other manufacturers, Qualcomm still managed to maintain its market share at the current level of around 40%. HiSilicon was a captive chip manufacturer for a mobile phone company and did not participate in the competition in the commercial chip market. The Intel basebands were exclusively supplied for Apple iPhones. The only mainstream sources of 4G baseband chips that were available to the other mobile phone manufacturers in the world were a few companies with core technical capabilities, such as Qualcomm, Marvell, MediaTek, Unisoc and Samsung.

In the 5G era, the development of baseband chips becomes much more technically difficult. In addition to its own 29 bands, a 5G chip is also required to be compatible with 2G/3G/4G networks and meet the high throughput and low latency requirements of the three major application scenarios, i.e., eMBB, mMTC and URLLC. This not only poses challenges to manufacturers in the aspect of 5G chip design architecture, but also requires the accumulation of baseband technologies in the 2G/3G/4G era. Therefore, only a few semiconductor manufacturers have managed to break through the technical barriers and commercialize 5G baseband chips. At present, there are only five manufacturers that have succeeded in developing 5G chips, including two captive manufacturers (HiSilicon and Samsung, Apple is still in R&D process) and three non-captive manufacturers (Qualcomm, MediaTek and Unisoc). In 2019 and H1 2020, the competition of 5G baseband chips mainly focused on high-end flagship models. As the production capacity continues to grow, it is evident that the target market of 5G baseband chips is moving downward, and all manufacturers are setting their eyes on mid-end chips. Due to the huge size of the mid-range market, the companies controlling this market will basically have greater say in the 5G era.

The R16 version of the 5G NR standard froze a few months ago, and R17 version will freeze by 2021-2022. This signals the beginning of another round of market competition. The target market will not be limited to mobile phones and other consumer products, but also cover IoT, industrial automation, smart city and other new application scenarios. Terminals with more diverse and demanding requirements will be equipped with 5G and other communication chips to support the entire digitization ecosystem. Such a huge attractive market will become the next high ground for which communication chip manufacturers will not hesitate to compete.

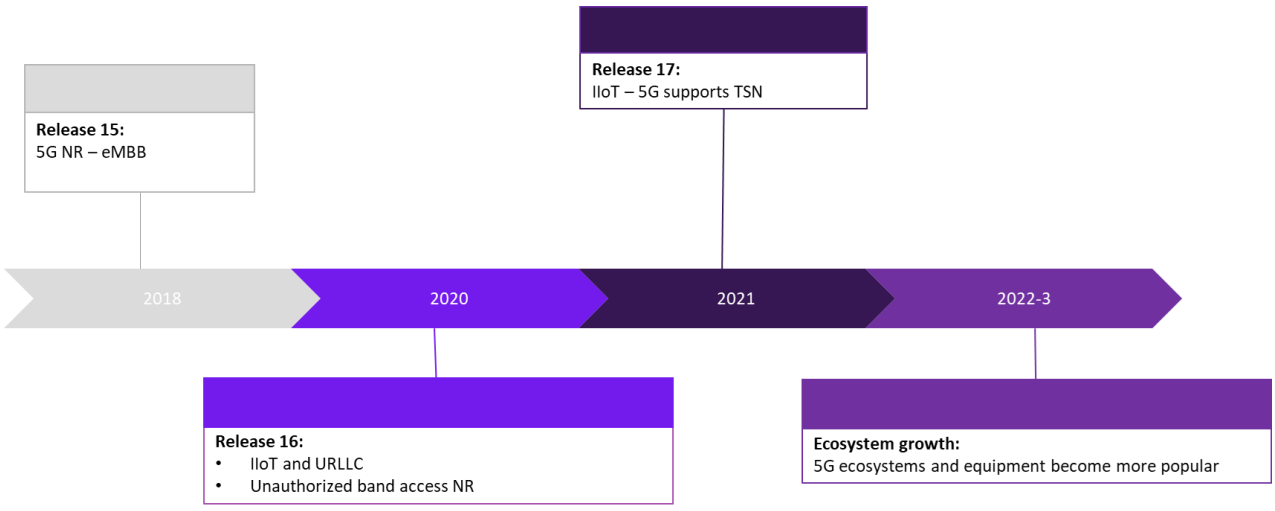

Figure 12 IoT-related 5G Standard Setting Procedure Which is Soon to be Completed

6.2. The Importance of Full-Range Communication Solutions in the 5G Era

After generations of 2G/3G/4G technology iterations, there are only a handful of companies that can fully participate in and successfully survive and grow in global competition. After entering the 5G era, cellular communication frequency bands are more abundant, technology is further complicated, and design and manufacturing process barriers rise. The ability to mass-produce 5G baseband or SoC chips has become a goal that the world's leading chip companies are scrambling to pursue. In addition to captive chip manufacturers such as Samsung, HiSilicon, and Apple, only Qualcomm, MediaTek, and Unisoc have become the three-remaining non-captive chip suppliers.

Although the current global 5G chip market is only shared by the few mentioned semiconductor companies with core R&D capabilities, such new markets are often not calm, especially in today's epidemic outbreak and global economic recession. Some semiconductor manufacturers are actively researching and developing relevant technologies, hoping to enter the market. Some mobile phone manufacturers also feel the pressure from the supply chain and the instability of the market macro-environment. Therefore, using one's own advantages, based on the existing market space, and seeking a broader market can help companies survive and develop better.

In the era of Internet of Everything, in order to strengthen the bearing of the broader digital world, chip companies need to deploy 5G technology in a wider range of IoT applications, and use their own communication baseband advantages and understanding of the wide range of applications to improve chip performance. At the same time, the power consumption needs to be further reduced, so that 5G chip is expected to be widely used in multiple vertical industries and terminal equipment, including communication modules, Mi-Fi, set-top boxes, AR/VR, IP cameras, industrial gateways, live broadcast machines, AGVs, Drones et cetera. For the time being, NPU-integrated SoC can better support complex AI applications with both

high performance and low power consumption, facilitate the realization of more artificial intelligence-based application scenarios on the terminal.

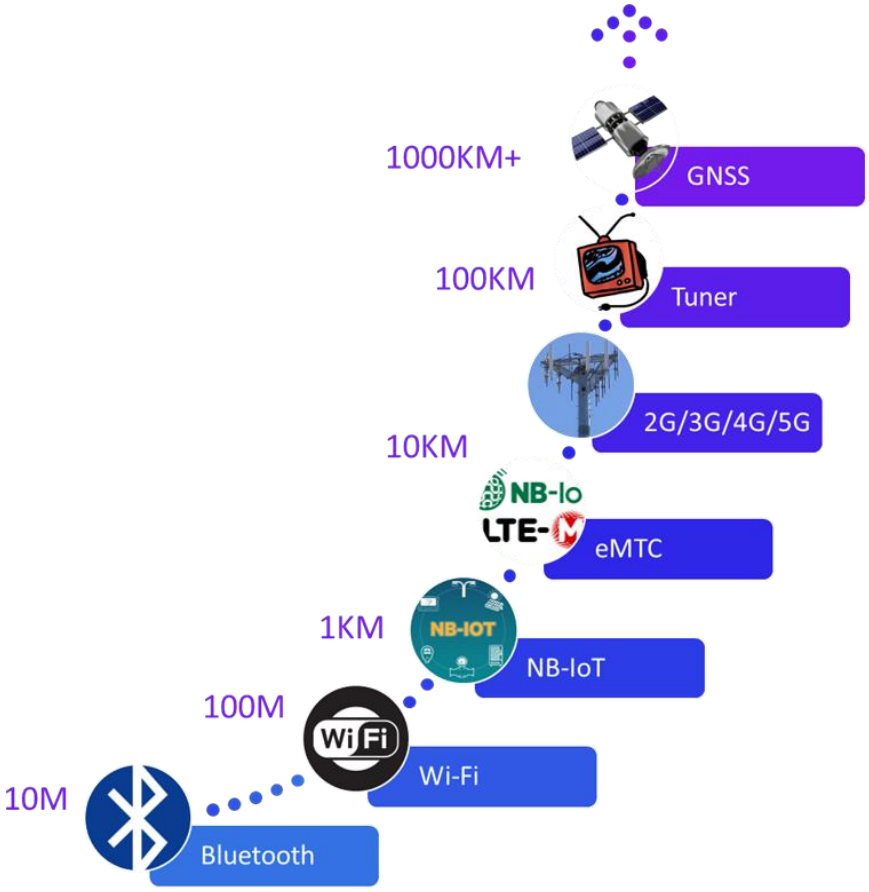

Figure 13 Interconnection technology solutions at different distances in a wider IoT network

In the meantime, chip companies should also focus on the market of an even broader IoT networks, including low communication rate applications (industrial IoT, warehousing and logistics, smart home, smart meter, etc.) that account for 60% of total connections , About 35% of medium communication rate applications (smart wearables, smart finance, networked vehicles, etc.) and about 5% of high communication rate applications (HD video surveillance, telemedicine, live video, etc.). Combining 5G/LTE Cat.6 with 2G/3G/LTE Cat.1/Cat.4, NB-IoT, Wi-Fi, Bluetooth, and even GNSS\LNB and other communication technologies at different levels and distances to connect. The characteristics give more vertical industries and terminal equipment, drawing a complete map of the communication chip carrying the IoT world.

7. Conclusion

Although widely affected by the epidemic, the global 5G deployment and terminal market has entered a critical year in 2020. The global 5G network layout is gradually taking shape, laying a preliminary foundation for the evolution of the interconnected world. The industrial ecology for the consumer market is also becoming mature, and the terminal industry chain has basically established a pattern of competition and cooperation coexisting. Participants realized that in order to build a new interconnected world, not only the large-scale deployment of 5G networks, but also the large-scale popularization of 5G terminal equipment and the improvement of application scenarios are required. Only when a complete consumer market is established, can the current and future massive network deployment scale be undertaken, and the society's absorption and utilization of 5G technology and sustainable development can be promoted.

The role of 5G communication chips in the entire new interconnected world is self-evident. As a key device for the connection of terminals and networks, the development cycle takes long, and the technology is difficult. It has become a gap that is difficult but must be crossed in building such a new ecosystem. Semiconductor manufacturers have conducted fierce competitions in terms of price, technology and ecology in recent years. In the competition, as the 5G communication chip technology gradually matures, and the price is further dropped, this technology is quickly decentralized from high-end models to mid-range models, further benefiting a wider user group. In addition, it also benefits connected devices other than mobile phones, helping to establish a complete 5G terminal hardware ecosystem.

With the competition of 5G mobile terminals, the market competition between non-mobile consumer terminals and enterprise IoT terminals is about to kick off. Compared with consumer applications, enterprise applications will face diversified standard requirements. According to different industries and use cases, communication requirements are also different. Compared with previous generation technologies, companies hope that 5G can provide better performance (data throughput, latency, etc.) and more flexible application methods to meet the different priorities of enterprise IoT. In order to achieve this goal, while technology research and development and standardization, the 5G industry needs to continuously prove the effectiveness and necessity of 5G to the vast number of potential user companies, so that the new value chain can be more deeply understood and accepted by the market.

In order to be able to continue to carry the interconnected world in the digital age in the future, chip companies need to evaluate all potential scenarios from a considerable height, and infer the future industrial business model, not only starting with 5G mobile phones, but also focusing on Other new types of consumer electronics, as well as the broader enterprise AIoT market, and an in-depth

understanding of the needs of extremely fragmented vertical industries. In such a future, 5G will not be an isolated solution, but a flexible combination of a variety of communication technologies based on specific requirements, which puts forward higher requirements for chip suppliers. Therefore, we should recognize the opportunities in the early market and the times in time, vigorously improve the ecological construction of chip products and a deep understanding of application scenarios, provide competitive solutions in advantageous markets and applications, and more firmly carry the future interconnected world .

Appendix

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