Intelligent Automotive Solution 2030

Building a Fully Connected,
Intelligent World

Contents

Foreword

ICT enables an intelligent automotive industry and helps carmakers build better vehicles

The beginning of the 2020s has marked a rapid shift towards more intelligent electric vehicles within the automotive industry. A new era for the automotive industry is just on the horizon, and we will soon see these profound changes affect our daily lives.

There is an industry-wide consensus that vehicles will be more electric and intelligent

Carmakers are embracing this trend by actively adjusting their business strategies and ramping up R&D investment. Many have made transformation a core part of their future development strategy and have already begun to take concrete steps in this area.

Technology and user experience are driving rapid growth in the new energy vehicle (NEV) market

In 2020, NEV companies were able to buck the trend and grow, helping them establish a mid- to long-term competitive edge over other players in the automotive market. This can be attributed to two key drivers – technology and user experience – that NEV companies have been able to leverage

through heavy investment into R&D and closer analyses of user requirements. According to China Association of Automobile Manufacturers, in 2020, 1,367,000 NEVs were sold in China, marking a remarkable 10.9% increase from the previous year, despite the overall 1.9% decline in China's passenger vehicle market due to the pandemic.

Data and software are turning traditional vehicles into intelligent and software-defined vehicles

Data and software support faster iteration of vehicle functions, helping vehicles deliver experiences beyond consumer expectations. New, ever-evolving functions and services are also providing stable revenue streams for carmakers, pushing the industry to move away from product-centered operations towards user-centered operations.

What it means to "build better vehicles" is changing dramatically for carmakers

Users are increasingly focused on intelligent and electric features, rather than the traditional mechanical aspects of a vehicle. To make great intelligent electric vehicles, carmakers need to use digital platforms to achieve faster vehicle development and improve efficiency at lower costs. They also need to enable fast software iteration, ensure vehicle safety and trustworthiness, and address other challenges that consumers might face. These are what it means to "build a better vehicle" in the era of intelligent electric vehicles.

In the future, the market for new intelligent connected vehicle components will be worth trillions of dollars. Huawei hopes to bring its decades of ICT expertise to the automotive industry as a provider of new components for intelligent connected vehicles. As vehicles become more electric and intelligent, Huawei wants to help carmakers build better vehicles.

Macro trends: Cross-sector collaboration for shared success

The automotive industry is changing rapidly, and so are its products and industry landscape. As ICT is integrated into the automotive industry at an increasing speed, cross-industry collaboration becomes increasingly important. Huawei is committed to researching basic ICT technologies and bringing its ICT expertise to the automotive industry through partnerships with carmakers.

Faster industry upgrade brings a bright future for electric and intelligent vehicles

Favorable policies create new opportunities for electric and intelligent vehicles

Carbon neutrality has become a globally recognized mission. Many countries are racing to become carbon neutral. The transportation industry plays a key role in this process as it presents huge opportunities to conserve energy and cut emissions. This in turn makes the NEV industry very promising.

The EU has tightened carbon emissions standards and increased penalties, significantly driving up compliance costs for traditional fossil fuel vehicles. As part of its broader efforts to stimulate the NEV market, the EU also now offers purchasing incentives and tax benefits for those who buy electric vehicles. Similarly, the US has released a 2030 plan for electric vehicles, and is currently accelerating the deployment of

charging infrastructure.

In China, low-carbon vehicles are playing a key role in the government's carbon peak and carbon neutrality ambitions. The transportation industry – the automotive industry in particular – is setting out a roadmap for reaching its carbon peak and carbon neutrality goals. The Chinese government has also tightened its dual-credit policy, which assesses carmakers according to their efforts to cut fuel consumption and produce NEVs. This policy has yielded positive results and stimulated significant investment into NEVs. China's big push for the electrification of public transportation is also driving NEV sales.

Many governments are fostering positive policies and regulatory environments for their intelligent automotive industry through independent research and policy guidelines. China, for example, has introduced many policies on intelligent connected vehicles in recent years, including specifications for vehicle quality and safety, functional safety, cyber security, data security, and road tests, which has facilitated the construction of demonstration zones for new products. Looking ahead, standards and regulation for intelligent vehicles will continue to develop in line with new technological advances. This kind of regulatory environment is critical to commercializing mature technologies and promoting sustainable growth in the intelligent automotive industry.

China's New Infrastructure Plan has laid out requirements for enhancing top-level designs for information, convergence, and innovation infrastructure, while improving underlying infrastructure like 5G, big data centers, artificial intelligence (AI), and charging infrastructure for NEVs. China is also promoting a new development model – the dual circulation model – which aims to create a powerful domestic market while promoting consumption and more room for investment. This new model will allow Chinese carmakers to compete globally and increase internal circulation through more domestic demand.

ICT accelerates upgrades in the intelligent automotive industry

The new vehicle lifecycle sees core functions continuously upgraded. This means vehicles need more sophisticated electrical/electronic (E/E) architecture, system on chip (SoC) computing power, software and data use, and cyber security. This is changing the automotive industry at a fundamental level, as it embraces more advanced ICT technologies and solutions.

Moore's law has long been the golden rule for the semiconductor industry, profoundly influencing the development of PCs, digitalization, Internet, and more for over 50 years. The next 10 years will continue to see Moore's law governing the development of computing power required for intelligent vehicles. Huawei predicts that that a vehicle will require more than 5,000 trillion operations per second (TOPS) of computing power by 2030 to enable the further advancement of telematics applications like intelligent driving, intelligent cockpits, and extended reality (e.g., augmented reality [AR] and virtual reality [VR]).

5G (including 5.5G) promises high bandwidth, low latency, and ultra reliability, making it possible to meet the essential connectivity requirements of intelligent vehicles. By 2030, intelligent digital platforms, powered by emerging technologies like 5G, cloud, big data, Internet of things (IoT), and optical technologies, will connect the physical and digital worlds for vehicles. This will greatly drive innovation and upgrade in the automotive industry.

Changes in supply: Vehicle sales will surpass those of fossil fuel vehicles by 2030

Advanced battery technologies and increasing electric vehicle supply will further drive down the cost of electric vehicles, giving electric vehicles a huge price advantage over traditional fossil fuel vehicles. The boost that China's New Infrastructure Plan has given to advancements in charging and battery swap technologies is making electric vehicle charging as easy as filling up a traditional gas tank.

Carmakers are rapidly expanding their presence in the NEV market. Jaguar will go fully electric by 2025, and other big players like Volvo, Bentley, BYD, and Geely have pledged to switch to fully electric vehicles by 2030. Volkswagen, BMW, and a few others expect half of their global sales to be fully electric by 2030.

According to China's State Information Center, Chinese car brands have managed to keep hold of a solid 35% of China's vehicle market over the past five years. The overall push to increase the quality of domestic manufacturing has also driven

Chinese carmakers to develop high-end brands that prioritize connected, autonomous, shared, and electric (CASE) vehicles. This has resulted in the launch of pure electric platforms, and a surge in in-house development and partnerships that integrate ICT to make vehicles more intelligent.

By 2030, the global NEV market, especially the Chinese NEV market, is expected to grow significantly, with global NEV sales outnumbering those of fossil fuel vehicles.

Changes in demand: Stimulating the intelligent electric vehicle market

User demand for intelligent electric vehicles is on the rise. As electric vehicles will soon cost much less and become more convenient, China is set to benefit greatly from its large consumer market. This gives the nation a base from which it can further develop intelligent electric vehicles. The Chinese market has long been less saturated than more developed markets, and Chinese consumers are also proving to be more receptive to new developments like electric vehicles and intelligent driving.

Due to China's constantly changing demographics, income structure, and consumer purchasing behavior, its consumption structure is also changing at a rapid pace. China will soon become a middle- or high-income economy, and consumption is expected to continue to grow as per capita GDP and household disposable income increases. Consumer distribution is also changing, which means demand is becoming more diversified. China's Post-2000 generation, a Gen Z analogue of true Internet natives, are big fans of new technology and individual expression. They represent a huge engine for growth in domestic consumption. A sliver economy – all economic activities linked to China's older age groups – is also emerging. The two- and three- child policy is also reshaping consumer demand.

Such changes in consumption structure will also affect car consumption, both directly and indirectly pushing China's vehicle market from relying on traditional models to digital models, from commodity-oriented to experience-driven, and from valuing commonality to valuing individuality.

Changes in product attributes: Reshaping the automotive value chain

Key vehicle differentiators: From powertrain and chassis systems to intelligence

As vehicles' power systems become electric, their powertrain and chassis systems will gradually become more standardized. This makes intelligent cockpits, intelligent driving, and other intelligent functions the key differentiators of vehicles. The intelligence level of vehicle cockpits and driving systems will become key factors in users' purchasing decisions. Over-the-air (OTA) updates will be used to deliver superior user experiences and further increase users' uptake of intelligent functions.

Such shifts also present an opportunity for carmakers to expand their hold on the vehicle market. As the laws, regulations, and policies on intelligent vehicles continue to improve and intelligent driving technologies become mature, autonomous driving will enter large-scale commercial use via robotaxis and closed or semi-closed low-speed driving scenarios by 2030 before gradually being implemented in passenger vehicles. In addition, human-machine interaction technologies will continue to advance and the intelligent cockpit application ecosystem will continue to improve, making vehicles an intelligent mobile "third space" outside of home and workplace.

A wider industry: From automotive products to all-scenario mobility services

5G (including 5.5G), IoT, AI, edge computing, and low-carbon technologies are still rapidly

developing, converging, and iterating. They are accelerating the automotive industry's CASE transition. How carmakers will commercialize intelligent vehicles in specific scenarios is becoming increasingly clear.

As intelligent driving technologies continue to improve in different market segments, scenario-specific autonomous driving applications will be become more widely adopted. New forms of autonomous vehicles will emerge for specific scenarios, and the connection between transportation tools across different scenarios will become more seamless. Autonomous mobility services will appear in every link of people's travel. This will fundamentally change how people travel, how people interact with transportation tools, and how transportation tools interact with each other, greatly improving "mobility-as-a-service".

People's basic mobility needs have gradually changed from owning different transportation tools for different scenarios to using integrated mobility solutions for complex mobility scenarios. Many third-party application developers are mobilizing industry resources to develop new service applications for different scenarios, with the purpose of seamlessly connecting different transportation tools and providing end-to-end intelligent mobility services for users. These mobility solutions and services are providing new revenue streams for the automotive industry.

New profit models: From hardware to software and services

As key differentiators for vehicles change and the automotive industry's reach expands, individual intelligent vehicles will become platforms for continuous value creation. This will reshape the automotive industry's standard business model and value distribution pattern.

Carmakers have long profited from one-off deals – multiplying the unit price by the total number of vehicles or hardware units they sell. Software-defined vehicles will turn software and services into new revenue streams for carmakers, and their profits will be determined by software fees

and car parc. Moving forward, data and software will support ongoing, OTA iteration of vehicle functions by allowing carmakers to remotely repair and upgrade products, and improve user experience. This will give users more flexible and operable service models, driving a shift in the industry from product-centered operations to user-centered operations. These revenue streams will also be more stable for carmakers.

The automotive industry as a whole will focus on the new operation and charging model created by intelligent driving as it greatly expands profits for carmakers. In addition, software-defined vehicles will reshape the value chain, and creating more opportunities to unlock value. This will attract more third-party developers and innovators to invest in the intelligent automotive industry, which will help improve the intelligent connected vehicle ecosystem and build a positive cycle of value creation.

Cross-sector collaboration will define the new industry landscape

Carmakers and tech companies work together to maximize their strengths

Intelligent vehicles are the product of multiple industries, built on the integration of core digital technologies (e.g., ICT, software, big data, and AI) and traditional mechanical technologies. Emerging carmakers are the frontrunners in the first phase of the CASE journey. However, other carmakers are also joining the trend and beginning to improve their core competencies in software, electronics, and big data.

Auto underbody solutions are slowly standardized, becoming a shared platform on which other industries can grow. Tech companies, from consumer electronics manufacturers to Internet companies, are taking advantage of this trend and expanding into the automotive industry either on their own or through alliances. These companies have large amounts of capital, strong experience in ICT, significant technological innovation capabilities, and huge brand recognition. Their entry into the industry is driving rapid development in intelligent connected vehicles and pushing the automotive industry towards CASE 2.0.

The automotive industry has been around for over 100 years, and carmakers have emerged as leaders in manufacturing, quality control, safety, and reliability capabilities. Tech companies, on the other hand, have amassed extensive experience and advantages in intelligent technology applications, such as AI algorithms and big data. Software-defined vehicles will significantly change how companies capture value, serve their customers, and build their talent mix. To meet increasing user requirements, all companies along the value chain should become more agile and adapt to this new environment.

Software and hardware will decouple and general platformization and standardization will continue. This means the only way forward will be to foster a more open supply chain system and adopt more flexible vehicle models. Carmakers and tech companies will need to maximize their respective strengths, while also relying on cross-industry partnerships to find new and innovative ways to achieve business and social value.

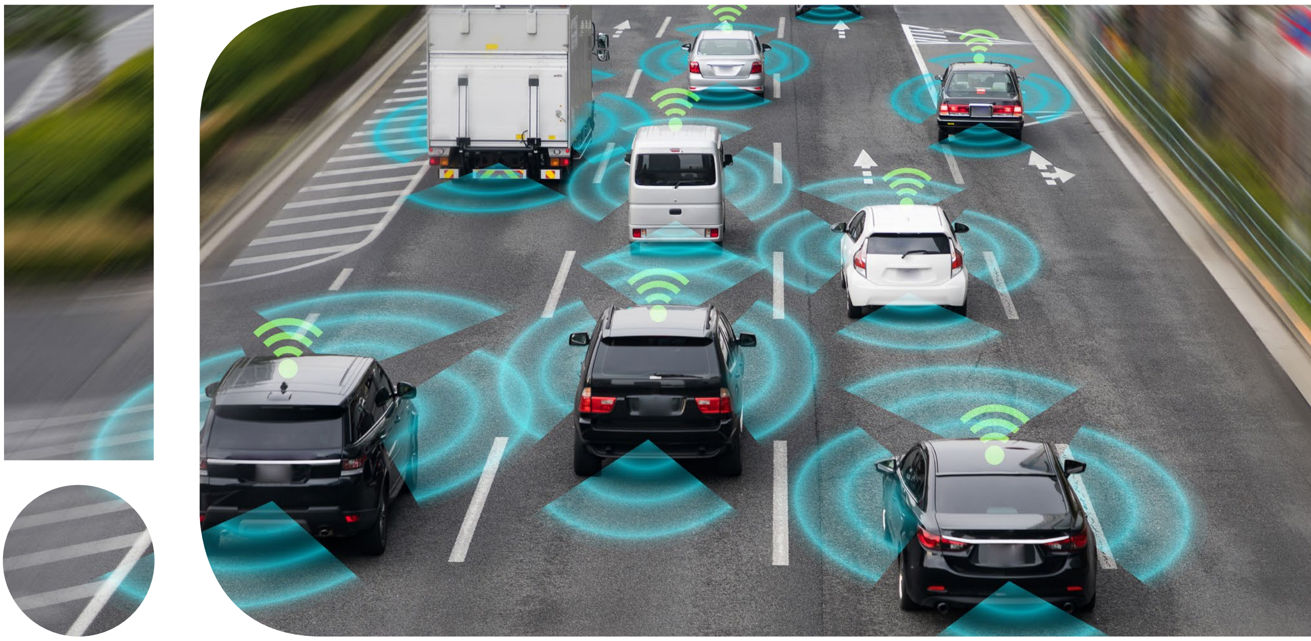
ICT is key to better travel experiences in the growing mobility sector

As the automotive industry's reach expands, demand for transportation and mobility services in new market segments will continue to increase. This will drive exponential growth in the forms and quantity of vehicles, as well as their related infrastructure. More and more traditional vendors are announcing transition plans to become "mobility solution providers", intending to tap into this huge new market. Different players will have different roles to play.

Mobility solution providers provide end-to-end solutions to meet user requirements across different mobility scenarios and control user traffic. Operators in closed scenarios understand operation requirements, customize the form factors of vehicles, and deploy infrastructure in closed scenarios. Carmakers use their existing manufacturing platforms and supply chains to manufacture these vehicles. Tech companies provide solutions like intelligent software and hardware, intelligent driving, and cockpit connectivity and control. Third-party ecosystem developers provide massive numbers of apps and deliver seamless travel experiences to users.

As the forms and quantity of vehicles continue to grow alongside their related infrastructure, we need to connect the vehicles and infrastructure in specific scenarios. Scheduling and connection across different scenarios, data sharing between different vehicles, and scenario-based smart service applications will need to be hosted on a cloud-based "brain". ICT will play a key role in connecting these disparate points and enabling scenario-based digital service sharing.

Intelligent driving powered by ICT will also make travel safer and more efficient. Long-distance driving will become easier and commercial use will become less costly and more efficient. Intelligent connectivity and spaces will make vehicles the real "third space", bringing more enjoyable experiences to users, so that users are willing to spend more time in their vehicles. By integrating people, vehicles, and home scenarios, carmakers aim to improve the in-vehicle user service ecosystem, provide intelligent services, and bring digital to every vehicle for a fully connected, intelligent world.



New scenarios: Bringing digital to every vehicle

As digital technologies are widely adopted and carbon neutrality has become a globally recognized mission, it is becoming an obvious trend that vehicles will become more electric and intelligent. Bringing digital to every vehicle will empower intelligent driving, intelligent spaces, intelligent services, and intelligent operations. This will allow for safer and more efficient transportation, greener and more convenient travel, more fun and intelligent lifestyles, and more efficient and lower-carbon operations.

Intelligent driving: Safer, smoother, and more efficient travel experiences

Intelligent driving can be divided into fully autonomous driving, highly automated driving, and advanced driver assistance systems (ADAS). Intelligent driving scenarios include closed roads, public roads, and other driving scenarios. Autonomous driving will disrupt the mobility industry and fundamentally change people's lives. The earliest applications have been on closed roads like high-speed roads and campuses, and will gradually come to cover public roads like those in urban areas. According to Huawei, autonomous vehicles sold in 2030 will account for 20% of new vehicles sold in China and 10% globally.

In 2030, robotaxi services provided by self-driving fleets are expected to cut labor costs and provide 24/7 mobility services that are more flexible and affordable.

Intelligent driving technologies will be integrated into existing modes of transport to provide safe,

efficient, and affordable mobility service solutions that meet different travel needs and deliver the best possible experience. Mobility resources will be centrally managed and data will be shared in real time, making it possible to build an end-to-end, point-to-point, and door-to-door mobility network. This will in turn help maximize the use of all available mobility resources.

When a user plans a trip, a cloud-based brain weighs up all the possibilities and, based on real-time awareness of the traffic situation, offers the optimal route and mode of transport. Diverse mobility resources will allow users to enjoy efficient, green, and safe travel while maintaining a dynamic balance in urban transportation capacity, contributing to sustainable urban development.

Intelligent spaces: From a flexible mobile space to an intelligent living space that integrates the virtual and physical worlds

Vehicles are no longer just a tool for transport. Their relationships with people and with their surroundings are changing dramatically.

Advanced intelligent driving technology will free commuters to enjoy work, study, entertainment, and much more within their vehicles. When vehicles serve as mobile offices – or even mobile living rooms – it will change how people think about their daily commute.

Powered by human-machine interaction, in-vehicle optical technologies, and immersive AR/VR technologies, intelligent cockpits will become multi-functional units. People will find themselves spending more time in their vehicles even when they do not want to go anywhere. For example, it will not be uncommon to see people sitting in parked vehicles watching movies.

The way we interact with our vehicles is about to experience three major changes. First, a cockpit will no longer be a combination of a steering wheel, an instrument panel, and a screen; it will integrate the virtual and physical worlds. Features such as voice control, facial recognition, and gesture interaction will make interactions simpler, more natural, and more efficient. What's more, it will not be long until brain-computer interfaces start seeing commercial application. Second, our vehicles will no longer passively await our instructions; they will intelligently

anticipate our needs. Technologies such as AI, biometric recognition, emotion perception, and vital sign monitoring will allow vehicles to better understand drivers' behavior, habits, and thinking, and become close partners that truly understand drivers' needs. Third, in-vehicle optical technologies will offer a richer spatial optical experience, and AR/VR technologies will further transcend the barriers of time and space. Such an immersive experience will drive broader and richer vehicle applications in both mobile and static scenarios.

An intelligent vehicle will become a truly intelligent space that integrates the physical and virtual worlds.

- **Driving:** The combination of in-vehicle sensors and wearable devices can accurately monitor drivers' health indicators, recognize fatigue, and send timely reminders to ensure safe driving.

- **Entertainment:** Passengers will be able to have true-to-life experiences of concerts and sports events without having to be there in person. A cinema will no longer be the best place to watch movies. AR technology will make gaming more immersive. Vehicles can become a personal entertainment space, a private cinema, an outdoor cinema, and a preferred place to play games with friends.

- **Mobile office:** Seats can be adjusted and rotated and windows can be used as large projection screens. A conferencing stream on a smartphone can be easily transferred to the vehicle, and the shielding function of the vehicle's sound zone ensures the privacy of the conference. Vehicles will become mobile offices, allowing professionals to get work done on the way to the airport, a restaurant, or their homes.

- **Social networking:** Drivers will not miss the beautiful scenery outside the window. Cameras mounted on the outside of the vehicle can be used to record, edit, and share beautiful moments. Getting stuck in a traffic jam no longer has to be boring. You can watch movies, play games, and make friends with nearby drivers using the head unit. AR/VR brings your friends within easy reach. With separate sound zones created within your vehicle, you will even be able to keep conversations private from other people in the vehicle.

Intelligent services: More intelligent scenario-based services

Digitalization is reshaping the world, and as a result, consumption patterns will change dramatically over the next decade. Services in all kinds of industries will be available online and become more customized, personalized, responsive, and scenario-based. As digital technologies are deeply integrated with vehicles, services will be intelligently and rapidly pushed to users based on the scenario they are in. This will be achieved in three ways.

First, as vehicles become more intelligent, interactions between users and vehicles will inform the services to be provided. Intelligent algorithms can identify, analyze, and understand users' interactions, predict their behavior based on their basic information and historical preferences, and provide the right services. Intelligent vehicles will continuously improve their understanding of users, in order to deliver better services.

Second, intelligent vehicles will make it possible to efficiently and accurately identify user needs in real time. By identifying and analyzing vehicle data, location information, and surrounding environments, intelligent systems can determine what scenarios users are in, proactively predict user needs, and provide the right services.

Third, brand-new, interconnected operating systems (OSs) can create more service scenarios, giving rise to an application ecosystem that is based on new modes of interaction. As the digital world approaches and the digital economy develops, a richer digital ecosystem is emerging to support all scenarios. In the connected world, more services will be provided by intelligent vehicles. The scenario-driven functions and services offered by connected vehicles will become increasingly intelligent, efficient, and convenient.

We can even imagine a situation in which a group of people would want a pizza while driving across town. Mobility-as-a-service providers will provide a shared vehicle that perfectly matches the passengers' preferences, select a high-rated pizzeria located along the planned route, and order the pizza in advance. The restaurant will then prepare the food, which will be collected by a drone. When the vehicle arrives at the designated handover location, its sunroof will automatically open and the drone will lower the food inside. This is a level of service that can only be achieved when every part of the process is seamlessly connected.

Intelligent operations: Autonomous driving is expected to be applied in commercial vehicles first, boosting the productivity of intelligent operations

Commercial vehicles are important tools for transport and the functioning of modern society. Their evolution into intelligent autonomous vehicles can help achieve the goal of carbon neutrality and boost work and operation efficiency while contributing to a more mature intelligent vehicle ecosystem. By 2030, commercial autonomous vehicles will be used on trunk lines and public roads in addition to closed areas and dedicated roads. This will make intelligent operations a reality and greatly increase productivity.

When autonomous vehicles are operated in a closed area, it is possible to enumerate all the scenarios in which a vehicle might find itself and foresee potential emergencies. For this reason, commercial autonomous vehicles will find their first large-scale commercial applications to be in closed areas like ports, mines, farms, campuses, airports, and closed scenic spots. In these areas, intelligent commercial vehicle technologies will not only be applied to transport vehicles; they will also be integrated with operations management systems to build

unmanned manufacturing systems where autonomous driving applications have been integrated into the core production systems that support transportation and distribution. This means intelligent vehicle technologies will be commercially used on a large scale.

By 2030, Vehicle-Road-Cloud collaboration solutions will make it possible for multiple autonomous vehicles to collaborate in closed areas, which means autonomous driving has the potential to be commercialized in vertical industries. Service capabilities, like comprehensive environment perception, global resource scheduling, dynamic service mapping, multi-vehicle cooperative driving, lane-level route planning, coordinated signal control, and service simulation testing, will further streamline service processes, make the collaboration between multiple autonomous vehicles a reality, and increase scenario-based operation and transportation efficiency. All of these will help cut costs and boost productivity.

Cloud scheduling and high-definition (HD) maps will be critical to the service management and scheduling of autonomous vehicles. When intelligent commercial vehicles are used in closed areas, operation managers will use the vehicle cloud control management system to schedule and monitor those vehicles, and support service and safety management using HD maps. In a port, for example, the operation control platform of an intelligent horizontal transport system will be connected to the terminal operating system (TOS), which means the scheduling of autonomous container trucks will be fully integrated into the automatic port scheduling system. This level of integration will help fully automate port operations. In addition, the dynamic layers of HD maps can be updated to reflect changes in the location and status of quay cranes, yard cranes, locking/unlocking stations, and container yards.

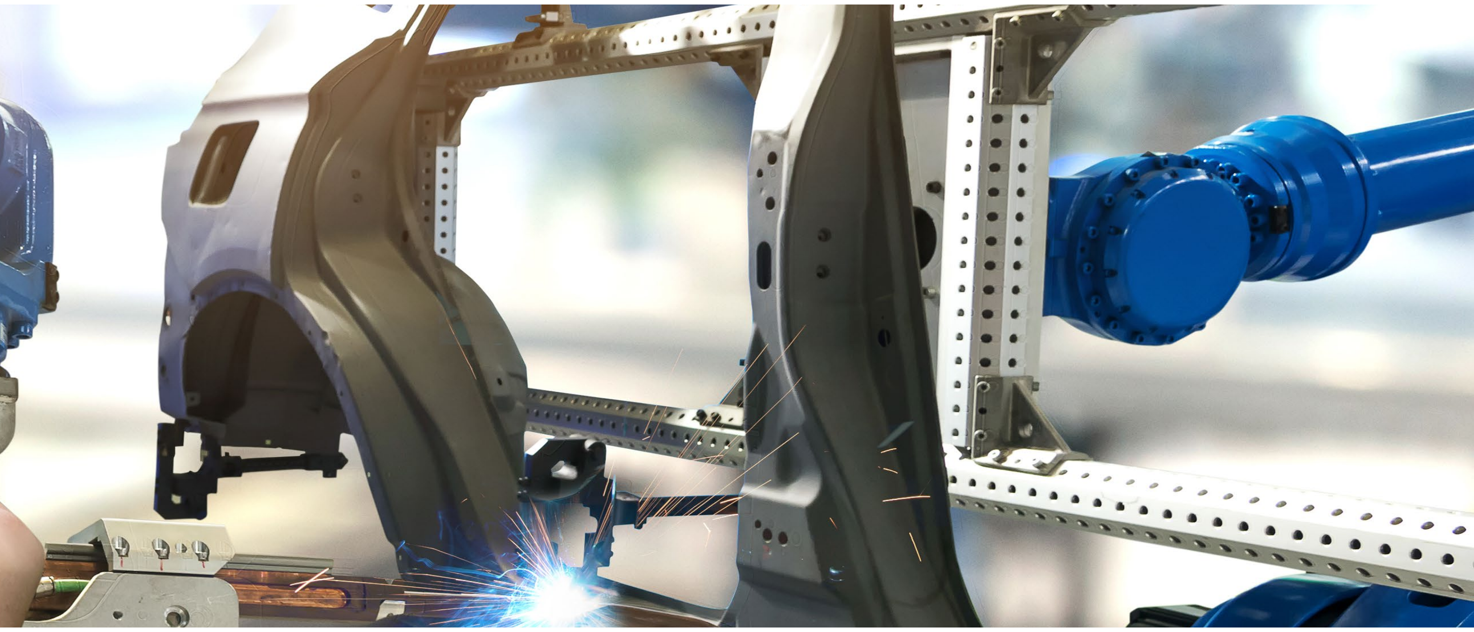
As road infrastructure is upgraded over the next decade, on trunk lines, commercial vehicles will gradually shift from assisted driving systems to fully autonomous driving. As electric vehicles are widely used in urban short-distance transportation, and roadside network infrastructure becomes more intelligent, the penetration rate of intelligent commercial vehicles is expected to rise sharply on more complex public roads, including urban roads. Building on the basic capabilities of autonomous vehicles and their potential commercial application, carmakers can work with ecosystem partners to build more viable intelligent driving applications to overcome the challenging scenarios faced by commercial vehicles.

Technology projection: New components will drive sustained innovation in intelligent vehicles

Evolving to a central computing and communications architecture for software-defined vehicles

Today, most vehicles still use a decentralized E/E architecture. Under this architecture, each separate function has an independent controller, so a vehicle has almost 100 controllers and over three kilometers of wiring. This makes vehicles costly and heavy, and difficult to automate vehicle assembly. In addition, electronic control units (ECUs) are often developed by different vendors, meaning they have inconsistent standards which carmakers struggle to develop new functions or perform OTA updates. In the future, intelligent connected vehicles will be even more complex. The volume of data collected by vehicle-mounted sensors will dramatically increase. This will raise the bar for real-time data transfer and data processing. These trends mean that vehicles' E/E architecture must evolve.

With the rapid development of digital and intelligent technologies, vehicle functions are becoming more integrated and centralized. There is a widespread understanding in the automotive industry that a decentralized architecture is no longer viable, and that it must evolve first into cross-domain architecture, and eventually into a single central computing platform. Vehicle



functions will become applications loaded onto a central processor so that they can share a single set of sensors and actuators. Components will gradually become more standardized. This will help reduce the cost and complexity of new function development in the long run. Meanwhile, domain controllers will evolve through the addition of new software features. By 2030, the E/E architecture of vehicles will be a computing and communications architecture that consists of a central computing platform, zonal control, and high-bandwidth in-vehicle communications.

High-performance central computing platforms power software-defined vehicles

Central computing plus zonal control, either in a hub-and-spokes or ring model, offers architecture stability and functional scalability. Within this architecture, new external components can easily be added from the gateway of the nearest zone, and with pluggable hardware, computing capacity can be upgraded as necessary, enabling simple iteration and upgrades of application software on the central computing platform.

The mobility scenarios are complex and subject to frequent change. New functions such as intelligent cockpits, intelligent driving, and vehicle control are constantly being developed. A high-performance central computing platform is required to support them. This platform can perform several thousand TOPS. It must be based on a powerful SoC with a vehicle-specific operating system, middleware, toolchain, and a centralized architecture. Such platforms will offer a stable architecture for software-defined vehicles, while still allowing room for smooth evolution. The chassis, powertrain, cockpit, and intelligent driving system will each place different demands on the central computing platform in terms of security, latency, dynamic response, and the supporting software ecosystem. A high-performance in-vehicle central computing platform will use hardware virtualization and a central functional safety framework, as well as AI algorithms to deliver the necessary levels of security and ensure that hardware resources are available as required for each domain. The technologies required include:

High capacity processors: SoC will deliver the thousands of TOPS of computing power required by the vehicle, including the chassis, powertrain, cockpit, and intelligent driving system. Key technologies needed to build SoCs include computing in memory and trustworthiness and functional safety islands.

High-speed concurrent processing for guaranteed low latency: High bandwidth is only part of low latency; an even more crucial factor is the capacity to process data in real time. High-speed concurrent processing enables central systems to simultaneously receive data from multiple sources. It prevents data surges, and will enable the vehicle to handle the data generated by an ever-growing number of apps and the ever-increasing demands on the system.

Hypervisor secure partitioning of hardware: The Hypervisor allows one physical server to function as multiple virtual servers and delivers customized functional safety for the different domains of a vehicle. AI engines monitor and forecast the workloads for different virtual partitions and dynamically schedule hardware resources, thereby achieving secure partitioning and load balancing.

Inter-app freedom from interference (FFI): The Hypervisor partitioning function delivers a secure silo of resources for the applications, communications mechanisms, OS, and hardware accelerators. Within the processors, a dedicated safety island provides a safety system that reaches the standards of 3-Level Safety Monitoring. The safety island's intelligent fail safe and fail operational functions enable coordination of the safety responses with other vehicle functions.

Building on a powerful central computing platform, the software-defined vehicle sector will concentrate efforts on agile development and real-time release of new functions to deliver the diverse experiences that users will demand of mobility.

In-vehicle, high-bandwidth, and multi-protocol networks for software-defined vehicles

The centralization of vehicle functions will drive substantial changes in the access approach and method used for communications. Vehicles will be divided into a number of zones, each with its own gateway. Zones will be defined by function, physical position, criticality, and safety. Sensors and actuators will be connected to the nearest access points to transfer data to the backbone network and then to the central computing platform. This approach will reduce the total amount of wiring required, and support the development of new functions. Sensors will no longer be limited to a single function, and actuators will not be bound to a directly connected controller.

By 2030, multiple access protocols will be in concurrent use. Local Interconnect Network (LIN), Single Edge Nibble Transmission (SENT), and Peripheral Sensor Interface (PSI5), though slow, will still be used because of their cost advantages. But ultra-high-definition (UHD) cameras, 4D imaging radars, and high-resolution lidars will require much more bandwidth. According to Huawei, in-vehicle network transmission speed per link will exceed 100 Gbps by 2030. Vehicle Ethernet will become standard, and optical technologies will be widely deployed in vehicles because of their high bandwidth, light weight, insensitivity to electromagnetic interference, and low cost.

Conventional communications technologies are predominantly signal-oriented, using protocols such as Controller Area Network (CAN) and LIN. This approach deeply integrates communications with vehicle component deployment and routing, creating a problem: A change of the transmit/receive nodes will lead to changes of all nodes along the route.

Ethernet communications are service-oriented and can effectively address this problem. When the transmit/receive nodes are changed, no other nodes on the route will be changed. This will:

- Decouple communications from vehicle component deployment and routing, making it easier to scale up.
- Make interfaces standardized and contractual.
- Achieve interconnectivity of in-vehicle services.

Once these technologies are realized, a point-to-point backbone network for software-defined vehicles can be created. The technologies that would be required for this include:

High bandwidth copper communications: Signal attenuation is significant in copper cable over even short distances. Enhanced coding and algorithms will be required for intelligent power distribution and high-speed, high-bandwidth Ethernet transmission (10 Gbps to 25 Gbps). This will provide the high bandwidth required by in-vehicle applications for backbone networks.

In-vehicle fiber communications: For bandwidths over 25 Gbps, copper is no longer an option, because of cost, engineering, and electromagnetic compatibility (EMC) challenges. This makes fiber an excellent solution. Fiber is cost-effective, light-weight, and is not affected by EMC issues. If solutions can be found for vehicle-related problems around temperature, vibration, and service life, optical fiber communications will be widely used in in-vehicle applications and support the evolution to higher-bandwidth communications.

Deterministic latency: Real-time communications protocol stacks as well as time-sensitive network (TSN) protocol suites at the transport layer will need to ensure end-to-end deterministic latency at the microsecond level for vehicles. Transmission policies can be designed for specific service scenarios to meet the needs of different communications functions.

New wireless communication technologies for high-quality in-vehicle connectivity

By 2030, in-vehicle wireless communications will remove all barriers to connection within the vehicle. Any component will be able to connect using sliced wireless capabilities, so that new vehicle applications can call on them as needed. A new air interface will be required to deliver extremely low latencies of less than 20 microseconds for unidirectional transmission, five nines reliability, synchronization accuracy within one microsecond, up to hundreds of connections

and concurrent service provisioning, plus end-to-end cyber security. This is the level of quality required for vehicle connectivity. Service-specific resource management mechanisms will support in-vehicle wireless connections. Wireless slicing will make many things possible, like lossless audio streaming, UHD video apps, and ultra-low-latency interactive games. By taking the collaboration of multiple information domains to the next level, the interior of a vehicle will become an infotainment center offering immersive sound, video, images, and even light applications and sensations.

In-vehicle wireless communications technologies will transform the in-vehicle networking and enable simple upgrades of various vehicle modules. The use of wireless in place of wired connections will address design, production, assembly, and maintenance challenges created by vehicle wiring, and put an end to the highly-coupled architecture that wired connections create. In its place will be a platform + modular communications architecture, which can be replicated across many different models of vehicle. The flexibility of wireless communications allows for a range of different architectures, providing standardized wireless access interfaces. When vehicle-mounted devices become modular, standardized, and plug-and-play, the costs of vehicle development will fall, and smooth and ongoing evolution of the foundational platform will be supported.

Decoupled, service-oriented architectures for software-defined vehicles

Vehicles are now digital, intelligent products. User values, preferences, and needs no longer require vehicles to be a tool for transport; now, as with the phone, users want personalized experiences. Smart technologies, personalized features, and user experience are now the key factors guiding consumers' vehicle choices. At the same time, hardware and the associated technologies that go into vehicles are becoming less easily distinguishable, and carmakers are looking to software and algorithms to create competitive advantages and deliver more value. All industry players are now pursuing software-defined vehicles.

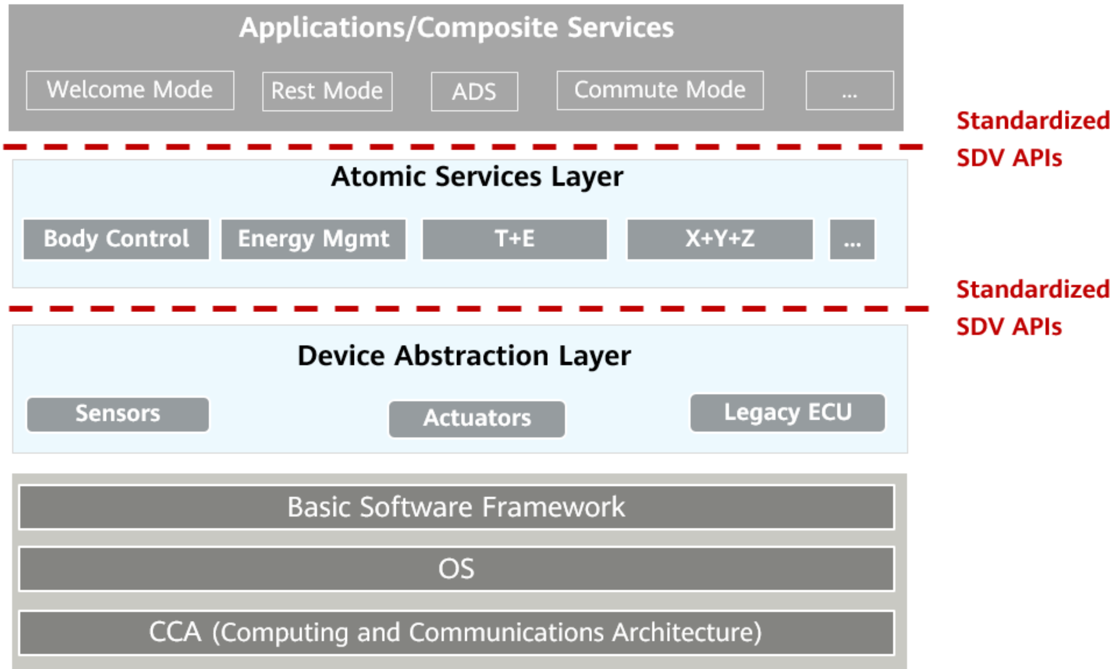
Being software-defined means that software is a key feature in a vehicle's concept, development, testing, sales, and after-sales services. It also means that the entire process will be constantly refined, with refreshed experiences and continuous value creation. A key feature of these vehicles is the decoupling of the software from the hardware. In terms of physical delivery, that means that the hardware and software are delivered separately. In essence, vehicle functionality can be expanded, software can be replicable and upgraded, and hardware can be swapped out or scaled up.

OTA updates can keep software at peak performance; plug-and-play components can be freely added to expand functionality. Flexible, scalable software-defined vehicle platforms will be used to help intelligent vehicles meet the challenges of complex use cases and growing demands on functionality. A service-oriented architecture (SOA), with decoupled layers of software, has also been recognized as the best option for general software architecture. To realize this architecture, the system will need to add a device abstraction layer and a layer of atomic services. (Fig 1 Service-oriented hierarchical software architecture)

Atomic services provide basic service capabilities. By masking differences in hardware, they enable upper-level applications to be replicable and portable across different vehicle models. The device abstraction layer normalizes the capabilities of sensors and actuators, so that software can be decoupled from the hardware, enabling plug-and-play replacement and upgrades of hardware modules.

Services will be decoupled from system design to create basic service units. Each separate hardware component will be abstracted into a standardized service component, and each service

Fig 1 Service-oriented hierarchical software architecture



component will provide one atomized function. These can be called on recursively and combined to produce complex functions, thus reusing the software as much as possible. Ecosystem partners can develop vehicle applications using platform components and standardized APIs that will then be managed by the vehicle platform. The platform will carry out app authentication, granting of access privileges, API call, security checks, and emergency management. Users will be able to choose vehicle apps the same way they do for their mobile phones. This will give users access to new vehicle experiences at very low cost: same vehicle, but a new journey every day! Developers, in turn, will benefit from consumers downloading their apps.

Whole-vehicle coordination and intelligent use of data deliver better safety

As a central computing architecture is more widely adopted, sensors and actuators will be standardized and plug-and-play, reducing the new vehicle development costs and delivering better reliability. Powertrain and chassis systems will be fully wire-controlled, with the control functionality increasingly separated from the mechanical components. The intelligent central computing platform will integrate modules from the engine, electrical system, heat, electronics, and information and communications modules. This will provide well-coordinated management of control functions, thereby delivering higher performance and more precise control. With increased centralized control over the vehicle powertrain and chassis, control latency will also decrease. Controller response time will be 1ms, greatly reducing execution latency. Coordinating control functions across all vehicle systems will continue to increase the value of the intelligent control system over time.

AI is the best way to control the vast streams of data that will come from vehicles and their surroundings. Data can be used to analyze the driving behavior of drivers, and develop a profile of an individual's driving style. If a driver deviates from this profile, the analytics system can issue warnings to the driver or even intervene to prevent accidents. Precision analytics can also help modulate vehicle controls for assisted driving. Using the central processor's built-in understanding of vehicle dynamics, the vehicle can optimize the driver's controls, and work with the driver to deliver a safer driving experience. For example, the vehicle could use its visual sensors and apply its understanding of the vehicle bodywork attitude, to make refined adjustments according to dynamic control principles to deliver improved precision in driving controls. It might notice if the road's surface becomes more slick, if the vehicle's weight is poorly distributed, if the vehicle yaws as it turns, and much more. Intelligent vehicles will sense the road's surface, external obstacles, the behavior patterns of surrounding drivers, and indicator lights, and combine all of this data to recommend corrective actions in the event of an emergency. They can then coordinate the vehicle's systems to significantly improve driving safety.

Intelligent driving: Making autonomous driving a commercial reality faster

Huawei uses sensor fusion technology to deliver superior safety in intelligent driving. Different types of sensors, including lidars, mmWave radars, ultrasonic radars, and cameras, are used to support the fusion and reconstruction of multi-dimensional environmental information.

At the perception layer, Huawei uses HD maps that will cover the entire world and integrated inertial navigation systems to support multi-source high-precision positioning. Coupled with AI chips that provide huge computing power, Huawei's intelligent driving solution can support sensor fusion in urban, highway, and parking scenarios. This further supports autonomous driving in complex road conditions.

Continuous algorithm training for better user experience and autonomous driving

There are still many technical challenges that need to be overcome if we want to make autonomous driving a commercial reality. Given the complexity of corner cases in real-road conditions and how difficult it is to collect long-tail data, perception algorithms, planning and control algorithms, and simulation and training algorithms will be crucial for autonomous driving experience.

If we look at sensor fusion algorithms, there are many technologies that determine a vehicle's ability to perceive and understand its surroundings. These technologies include a vision-based perception framework, lidar point cloud generation and enhancement, lane-level traffic light processing in complex light environments, flashing and fuzzy light source processing, color processing, light source luminance differences, overlapping object recognition, and vehicle interaction prediction.

As perception and prediction both involve uncertainties, the industry needs to further develop core planning and control algorithms that deal with multi-object and multi-stage game-theory decision making, motion planning, human-like decision making and planning models in complex interactions that involve object risks and scenario risks, and extraction and automatic labeling of key scenarios from massive amounts of data.

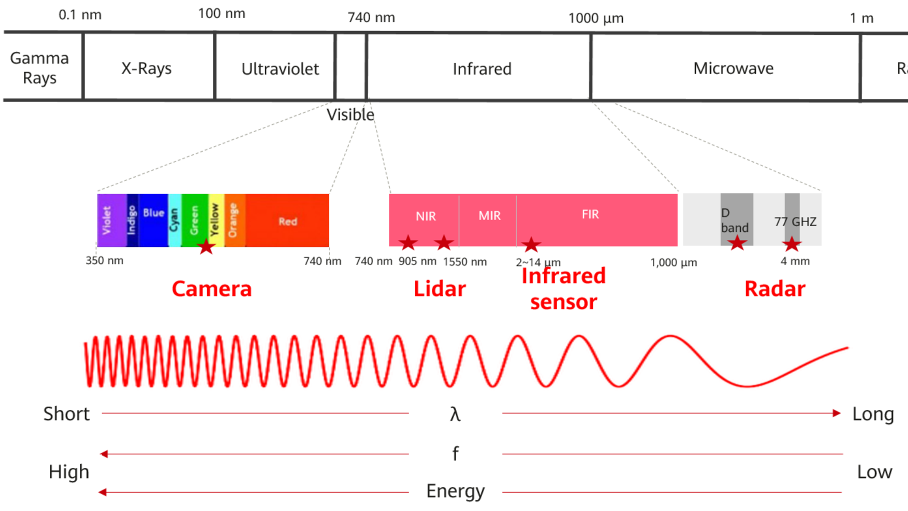
It will also be necessary to build a model for interactions between different traffic participants, create large-scale simulation scenarios, and ultimately form a comprehensive, high-fidelity simulation system.

Developing full-spectrum perception capabilities to make everything sense

As the automotive industry becomes more intelligent, perception systems become increasingly important. One day, they will be a cornerstone of intelligent driving. Ideally, the sensors that enable these systems will reach full coverage and cover all objects, all scenarios, and all weather conditions.

- **All objects:** People, vehicles, obstacles, road

Fig 2 Frequency bands for sensors



facilities, structures, etc.

- **Full coverage:** 360-degree coverage without dead zones.
- **All scenarios:** Highways, urban areas, traffic jams, accident scenes, and construction zones.
- **All weather conditions:** Day, night, rain, snow, fog, strong light, low light, and other harsh environments.

However, the industry still has a long way to go before it can make ideal sensors a reality. To make this happen, perception capabilities need to be built based on all sections of the spectrum. (Fig 2 Frequency bands for sensors)

1) Radars: The shift from the 77 GHz band to D band (110 GHz to 170 GHz) will significantly improve resolution

Radar sensors can perform consistently in all weather conditions because they work on super-long wavelengths. These systems excel in measuring velocity, so they can create unique value in dynamic and static separation and simultaneous localization and mapping (SLAM). However, currently, their poor resolution is limiting their use scenarios.

Radar resolution can be improved by utilizing either ultra-high bandwidth or large-scale antenna arrays. According to existing international standards, the 76 GHz–81 GHz frequency bands are already allocated to automotive radars. This means high-range resolution can be achieved through the higher 4 to 5 GHz spectral band. Angular resolution is determined by antenna arrays, which means the more antennas allocated for transmission and reception, the higher the angular resolution. Current radar systems still use three transmitting antennas and four receiving antennas (a 3T4R antenna array). Huawei recently improved on this by launching a 12T24R antenna array radar. However, the antenna arrays used in wireless communications have already reached 128T128R configurations.

Automotive radar sensors need to be physically small, which means the door-size antennas used in wireless communications systems are unsuitable for automotive applications. These size restrictions and the 77 GHz wavelength mean that antenna arrays for radar sensors would be 48T48R to 64T64R, at maximum. The shift towards higher frequency bands will continue. The D band (110 GHz to 170 GHz)

provides ultra-high bandwidth and has generally not yet been allocated or used for other services. The 140 GHz band is still being researched, but has a relatively suitable atmospheric window, so its propagation is less attenuated. What's more, wavelengths in this band are reduced by half. That means imaging radars that use an ultra-large 128T128R antenna array can be used in a limited space while still delivering high resolutions.

2) Lidar systems are moving from the 905 nm wavelength with time of flight (ToF) to the 1550 nm wavelength with frequency-modulated continuous waves (FMCW). Lidars are being integrated with chips, and high-performance 4D lidars will be widely adopted.

Thanks to their relatively mature components, 905 nm lidars have already been widely adopted and are ready for mass production. From a technical perspective, as the industry moves from analog to digital and from discrete to integrated, the transmitting and receiving components are being arranged in arrays, and core modules will be integrated directly into chips. These trends mean high-performance, low-cost, highly integrated, and highly reliable lidars may be the way forward.

Most light at 1550 nm, a near-infrared band, is blocked by human cornea before it reaches the human retina, which means it does not cause much damage to human eyes. Because of this, the 1550 nm band allows lidars to transmit at higher powers, which can greatly increase coverage. In terms of modulation, FMCW's use for radars can also be applied to lidars. FMCW lidars deliver better performance through high-performance 4D imaging (which can be used to measure velocity), strong anti-jamming capabilities, and higher sensitivity and dynamic range. In addition, FMCW lidars can be mass produced at lower costs, when combined with silicon photonic and optical phased array (OPA) technologies.

However, FMCW technology at the 1550 nm wavelength is far from ready for commercial use and will require concerted efforts from across the entire value chain to develop further. Further exploration of silicon photonic technology in line with Moore's law is one way that can help support FMCW. More complex and discrete optical functions can also be integrated into silicon-based chips, making lidar sensors more integrated, more affordable, and smaller.

3) Cameras will integrate visible light and infrared thermal imaging technologies to work in all weather conditions.

Cameras are a type of passive sensors and are most similar to the human eye. They can sense

surrounding objects through catoptric imaging. As one of the three major types of sensors used in vehicles, cameras are the most critical for identifying elements in a static environment, like traffic lights and road signs.

However, cameras also have drawbacks. The performance and confidence of catoptric imaging suffers at night and in low-light conditions, and heavy rain and snow can impede a camera's line of sight, greatly reducing its visibility. Cameras cannot independently overcome these harsh weather conditions.

However, in the infrared spectrum (in the 2–14 μm band) right next to the visible spectrum, a thermal emission imaging system can be used. Sensors that work on this band have effective night vision, and can detect objects through rain, snow, sand storms, and fog. They even have certain perspectives to further meet the requirements of all weather conditions. Vehicles are now starting to come equipped with infrared thermal imagers that have night vision, but this application still needs a low-cost solution for mass production.

Full convergence: Accelerating innovation in sensor form factors for simplified deployment

As vehicles become more intelligent, the number of sensors per vehicle is increasing dramatically. Vehicles come equipped with many sensors, from 1V and 1R1V to 5R5V and 6R13V3L configurations, and more will be deployed in the future. Here, R refers to radar, V means vision (i.e., camera), and L means lidar.

However, a vehicle's body is limited in size, and the installation and deployment of sensors raise even high requirements for body design, such as strict requirements on fascia, thickness, installation intervals, and flatness. This makes the entire style and design process much more difficult, because designers must balance vehicle appearance and sensor performance.

To make sensors easier to deploy in vehicles, innovation in form factors is a must. Miniaturization of sensors will be the way forward. In addition, sensors will need to be designed to better fit vehicle styles. Integrated designs that consider both sensors and vehicle style can greatly reduce the constraints on the vehicle body. This requires joint efforts from multiple sectors including materials, processes, and engineering.

1) Distributed antennas and central computing

Radars generally come in an integrated design that encapsulates front-end antennas and back-end signal and perception processing units into one box, to support point cloud generation, object detection, and perception processing. As central computing becomes more common, radar signals can be segmented and extended using the techniques already utilized in Huawei's distributed base stations. Conventional monolithic radars can be used only to generate point clouds, while perception processing units can be integrated with domain controllers. Radars that use distributed antennas and central computing deliver better performance, consume less power, and occupy less space than current radars. Solid-state lidars can also be deployed in a similarly distributed manner.

2) Integration into the vehicle body

An alternative solution for separate deployment is integrating sensors with existing components into vehicle bodies. Shark fin antennas already support GPS, 4G/5G, and frequency modulation. Surround-view cameras are also already integrated into rearview mirrors. Similar solutions can be implemented in the future, such as installing lidars into front-view headlights, integrating distributed antennas into glass components and doors, and combining far-infrared sensors with existing cameras. Such combinations can make sensors more adaptable and easier to deploy, but they also raise the bar for sensors. More effort is needed to address heat dissipation, interference, EMC, and other related issues that may arise from such convergence.

Sensors can also be integrated with each other. Low-cost distributed inertial measurement units (IMUs) can be physically integrated with sensors, which can help change sensors' motion compensation from inter-frame compensation into intra-frame (signal-level) compensation and improve the accuracy of sensor attitude perception. This model can help further improve sensors' overall performance and safety in scenarios like vibration, dead reckoning, and slopes.

3) Surface-mount sensors will reshape sensor deployment

Surface-mount sensors are the ultimate vision for future sensor deployments. Such sensors would need to be smaller and flatter, and eventually plug-and-play. Highly integrated chips would be necessary for this solution, as well as:

- **Microlens array technology:** An assembly of precision-manufactured microlens, just a few millimeters deep and high, used to project a tightly-focused beam. This can massively reduce the focal length between light sources and lenses, making flat designs possible. Though this technology is now mainly used in projectors, it also provides a new possible path for miniaturized lidars and surface-mount sensors.

- **Smart Skin (conformal antenna) technology:** An antenna array designed to conform to the shape of the carrier. This allows an antenna array to be directly attached to the surface of a carrier like a Band-Aid, so that the antenna array can be integrated with the platform structure. In order to work on surfaces with different curvatures, antennas need to detect a surface's curvature according to its bending state and automatically correct the phase of electromagnetic waves. This can maximize the gain effect, make sensors more adaptable, and add more flexibility in vehicle style design.

New technologies (e.g., microlens arrays, smart skin/conformal antennas, and silicon photonic technology) create unlimited possibilities for sensor integration in future intelligent vehicles. In the future, sensors will be like a layer of skin attached to the outer surface of intelligent vehicles. To make this vision a reality, all players along the value chain need to work together to advance in multiple fields, including materials, processes, and engineering.

Central computing platforms: Providing

large computing power to support intelligent driving

Powerful computing platforms will provide the fundamental computing power needed for intelligent driving. More sensors, both in type and number (over 50), will be deployed in a single vehicle to enable intelligent driving in all scenarios in complex road conditions. This includes 100-million-pixel cameras, event cameras, 4D imaging radars, high-resolution lidars, ultrasonic radars, infrared detectors, and sound detectors. In addition, all of these sensors will be increasingly accurate. These sensors will generate massive amounts of data that needs to be analyzed and processed in real time.

With improved chip processes, a vehicle will come equipped with a computing power of over 5,000 TOPS and over 3 million Dhrystone million instructions executed per second (DMIPS). When combined with computing in memory technology, the energy efficiency ratio of new vehicles will be further improved. These central computing platforms will provide the computing power needed to enable intelligent driving.

HD maps: New digital infrastructure to enable everywhere intelligent driving

By 2030, next-generation HD maps will become an essential digital infrastructure that enables the widespread deployment of intelligent driving. The shift from navigation maps to ADAS maps makes real assisted driving and energy-efficient driving possible for commercial vehicles. The current evolution of ADAS maps into HD maps will allow intelligent vehicles to hit the road.

The HD maps that we are currently using for intelligent driving provide HD static environment information, like lane-level road networks and basic road facilities, and positioning layer information, like vector features. This information can support high-precision positioning through map-matching, environment perception assistance, and lane-level route planning for intelligent driving vehicles. With these functionalities, HD maps become an integral part of the current intelligent driving system. By 2030, the next-generation of HD maps will cover all road networks, and 100% of roads with physical lane marks will be precisely digitized. Furthermore, lane-mark free roads will be given virtual lane indications. Elements that highly impact driving safety will be updated in real-time, while the dynamic layers of HD maps will be created, including layers for dynamic traffic events, real-time non-line-of-sight traffic participants, and semi-dynamic traffic environments (e.g., road conditions). Reference layers for dynamic behaviors, positioning outputs, and planning results will also be created and regularly updated to support safer intelligent driving.

Huawei will leverage its expertise in AI chips, algorithms, standardization, and ecosystem construction to create a next-generation HD map system that features advanced sensing, AI, and high-reliability positioning technologies to serve as the new digital infrastructure for intelligent driving by 2030.

V2X cloud brain for multi-vehicle collaboration and intelligent driving

Connected infrastructure is continuing to improve, and intelligent driving is already being adopted in more scenarios. The challenge we face is no longer just making single vehicles intelligent. Now, we want to make vehicles that cooperate with each other. This will push commercial intelligent driving and intelligent transportation to the next level.

Ubiquitous V2X connections need to be built to intertwine people, vehicles, and road infrastructure. A vehicle-road intelligent cooperative driving platform needs to be established on the cloud to streamline end-to-end application scenarios. Thankfully, multi-vehicle cooperative intelligent driving will quickly become a commercial reality, thanks to services like comprehensive environment perception, global resource scheduling, dynamic service mapping, multi-vehicle cooperative driving, lane-level route planning, coordinated signal control, and service simulation testing.

A cloud-based brain can integrate all the necessary information elements of people, vehicles, roads, and environments, improving vehicles' ability to perceive dynamic traffic environments. A cloud-based brain can also share driving strategies between different vehicles, allowing vehicles and traffic infrastructure (e.g., traffic lights and signs) to work in synergy. This allows us to optimize overall (not partial) driving strategies and further promote the development of intelligent transportation systems.

Intelligent cockpits: AI speeds up software and hardware upgrade

The vehicle cockpit is a hub where a user interacts with their vehicle. By 2030, more than 90% of vehicles will have an intelligent cockpit and from now onwards, we expect to see a new intelligent mobile device ecosystem gradually take shape.

Whether an intelligent cockpit can create a superior experience depends on its hardware and software, especially the chips and OS. In addition, the advancement of intelligent peripherals and in-vehicle perception algorithms will ensure users always have fresh experiences along the way.

Open cockpit OSs for an ever-evolving application ecosystem with brand-new experiences

Compared with smartphones and other consumer devices, an intelligent cockpit has more peripherals and supports multiple users, multiple concurrent operations, and multiple ways to interact. An intelligent cockpit has many components, including an instrumental cluster and an in-vehicle infotainment system. Its OS must be designed and developed in ways that support interactive experiences and ensure safety.

By 2030, cockpits powered by new quality of service (QoS) technologies and a multi-kernel OS structure for better software-hardware isolation will be able to schedule and deploy resources more flexibly across domains. In addition, convergence of different domains will drive down the cost of system evolution and contribute to a thriving ecosystem.

An ever-evolving application ecosystem is vital for cockpits to bring brand-new experiences to users. This raises the bar for the consistency and stability of cockpit OS's application interfaces.

At present, the cockpit OS market is plagued by the fragmentation and customization of solutions across the industry. For example, when a carmaker is developing a function that needs to work with a camera or microphone, they have to create unique versions of the function for different vehicle models because each hardware platform is different. This fragile approach to software development prevents different hardware components from effectively connecting with each other or sharing software capabilities.

There is yet another challenge for carmakers in software development. The work is outsourced to multiple vendors, with each being responsible for different functions, and redundant copies of the same function may co-exist. This creates chaos in version management, leads to a lot of extra development work, and complicates software upgrade and maintenance.

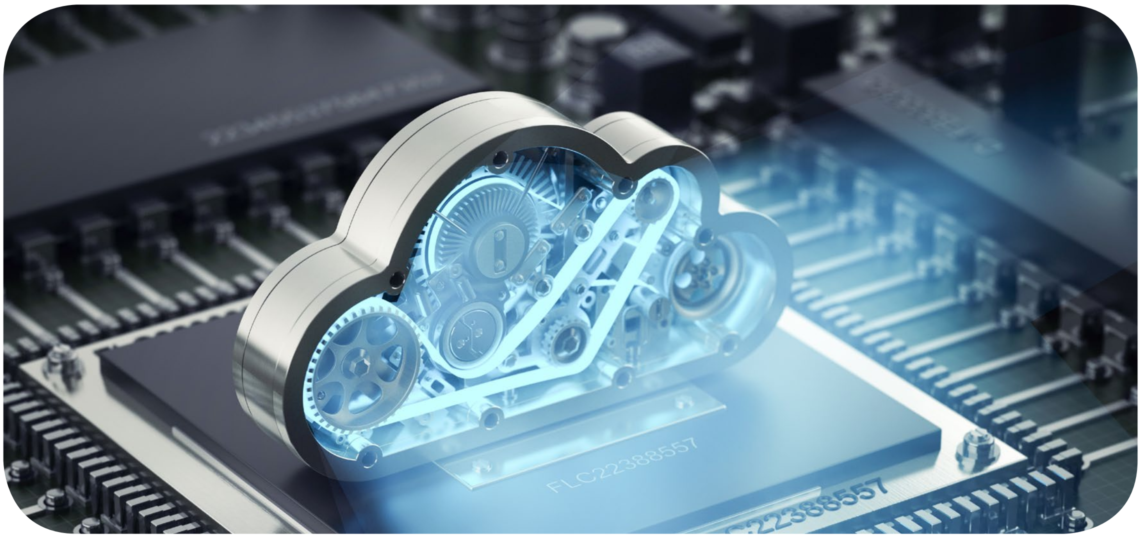
In the future, intelligent cockpit OSs will provide developers with unified APIs that are necessary for a thriving and ever-evolving application ecosystem. Providers of intelligent cockpit solutions will have to upgrade their platforms, open development suites, and other capabilities designed for application developers. In this way, cockpit solution providers will hone their own tech strengths and help developers create, promote, and monetize applications more rapidly. When providers of intelligent cockpit solutions work closely with developers, they can unleash the power of innovation to provide users with more appealing content, services, and experiences.

Intelligent sensing: AI-powered interaction algorithms for an unprecedented level of experience

By 2030, cockpits will have become more intelligent with the addition of new intelligent peripherals (e.g., transparent screens, AR-HUDs, holographic projectors, smart wearables, mmWave radars, and ToF cameras) and AI-based sensing and interaction technologies (beyond just voice and haptic). These peripherals and AI technologies will take the interactive cockpit experience to a new level, in terms of driving safety, in-vehicle communications, infotainment, and other aspects.

Today's in-vehicle voice assistants take the form of 2D virtual figures on the screen. Going forward, they will become 3D holographic robots, supported by mature media-less hologram projection technology. Users will be able to customize the appearance of the 3D robot. The robot will be incredibly expressive both emotionally and in terms of actions. Thanks to AI, the robot will be able to speak naturally, as it will not be subject to very limited programmed phrases.

More advanced hologram technology will enable



a vehicle to project information anywhere within its interior. While you are on a video call, the vehicle will project a hologram of the caller, who "sits" right next to you and talks to you "face to face". While in transit, the vehicle projects information in places that are convenient for the driver to see. Users interact with vehicles just as people naturally interact with each other.

Technologies that support main interaction capabilities, such as voice, visual, and audio, will evolve further. Specifically:

Voice: If we look at driving safety, voice will be the most important interaction capability of intelligent cockpits. Going forward, voice experiences will evolve to be more intuitive, agile, seamless, flexible, and emotionally resonant.

- **Intuitive:** Clear, easy-to-understand content for voice interaction, so that users can act without a second thought

- **Agile:** Efficient execution and timely feedback

- **Seamless:** A unified voice interface that provides seamless access to services across platforms

- **Flexible:** Easy manipulation of the interaction process and retention of the interaction status, and interactions are never abruptly ended

- **Emotionally resonant:** Voice assistants that resonate with users on an emotional level and promote brand image

In the future, voice-based interactive experiences will get even better with improvements in areas like front-end noise reduction, speech recognition (e.g., through visible and conversational assistants), generic voice understanding, and emotion-rich natural conversation.

Visual: The second key way that vehicles interact with users will be through vision. Currently, in-vehicle visual recognition technology is mainly used for the driver monitoring system, cockpit monitoring system, and detection and recognition of human-machine interactions (e.g., through gestures). In the future, more advanced visual recognition technologies will emerge to deliver functions such as detecting living beings in the vehicle, monitoring users' health, and enabling secure payment, entertainment, and integrated audio-video services.

Users will be able to interact with their vehicles in new ways, with vehicles providing more precise and convenient services. For instance, eye tracking technology and AR-HUD will work together to identify objects within eyesight in real time, and then project information about the objects, such as their details and relevant ads. When vision-based gesture recognition technology is used in conjunction with mmWave radars, the accuracy of gesture recognition will be improved and users will be able to smoothly interact with their devices. When there is a lot of background noise, integrated visual-audio technology will read the user's lips and translate lip movements into commands, supporting speech recognition and vehicle control across all scenarios.

Audio: Intelligent cockpits of the future will possess more advanced capabilities in terms of sound pickup and noise reduction, sound zone, and active noise cancelation.

- **Sound pickup and noise reduction:** The quality of in-vehicle phone calls and the accuracy of speech interaction will be improved by filtering out background noise.

- **Sound zone:** By analyzing audio signals before they are sent to the amplifiers, the vehicle can create multiple isolated sound zones, so that all passengers can enjoy immersive, multichannel stereo sound without disturbing each other.

- **Active noise cancelation:** This will continue

to be the next big thing for in-vehicle audio technology over the next ten years. More advanced hardware and algorithms will be needed to thoroughly cancel out the noise generated by the vehicle engine, road traffic, and wind, in order to make driving more comfortable.

Over the next decade, breakthroughs in components, algorithms, and architecture will take in-vehicle audio to a new level, transforming vehicles into mobile entertainment hubs.

Hardware plug-and-play: Standard interfaces keep user experiences fresh throughout hardware lifecycles

Consumer devices like smartphones usually last two to three years, and their software and hardware integration packages are small. Vehicles have a longer lifespan, including a sales window of 5 to 10 years and a useful life of 10 to 15 years. Carmakers tend to research and develop multiple vehicle models at the same time, so they have no choice but to simultaneously maintain a whole range of software and hardware versions.

As novel applications appear, hardware performance needs to keep up. For example, chips and other key components like cameras and displays will have to stay up-to-date throughout a vehicle's lifecycle. Cockpit hardware upgrading will lead to new business models in the post-sales stage.

Inside a vehicle, chips or chip modules must be able to meet the computing needs of software and hardware for the next three to five years. The chip module itself needs to be designed for backward and forward compatibility, so as to ensure easy upgrade (e.g., through pluggable components) and strike a balance between hardware lifetime and computing demand. Hardware plug-and-play is essential for this type of chip module.

When a key peripheral is replaced by a new one, it is necessary to install a new driver to support the new peripheral. Carmakers should aim to make this process as simple as installing a new driver on a Windows operating system. Also, it should allow OTA updates for certain parts of the cockpit OS. To make this possible, unified standards should be established for the interfaces of cockpit hardware, in order to eliminate issues caused by customized interfaces of head units, cameras, displays, HUDs, intelligent seats, intelligent steering wheels, in-vehicle robots, intelligent windows, holographic projection hardware, etc. To standardize cockpit hardware, the automotive industry needs to double down on standardizing communications interfaces, including those for short-distance wireless communications, wired communications, video, and audio. Standardization is key to driving down component costs and cultivating a hardware ecosystem.

Multi-device collaboration through distributed technology for seamless intelligent experiences

Intelligent vehicles are integrated systems, and how they interact with users will involve the broader surroundings. Connection and interaction of devices depends on both general-purpose cloud technology and a distributed software bus. Huawei's HarmonyOS for Automotive provides a distributed software bus to create a seamless experience across nearby devices, making it easier and more comfortable for users to interact with their devices. Huawei's distributed platform enables multiple devices to work together across scenarios, such as transit, office, and home. This creates an intelligent cockpit service system that delivers superb experiences for users in all scenarios, no matter what devices they are using at the time.

Imperceptible sensing and zero-wait transmission are the deciding factors for realizing seamless experience across nearby devices. If we are to meet these preconditions, we must first devote efforts to answering the questions of how different devices should discover and connect with each other, how connected devices should come together to form a network, and how transmission between devices that use different protocols can be realized. The key technologies here include automated device discovery, connection, networking (e.g., multi-hop automated networking and multi-protocol hybrid networking), and transmission (e.g., diverse protocols and algorithms, and intelligent perception and decision making).

A distributed software bus connects different types of devices by using a "protocol shelf" and a software-hardware collaboration layer, despite the different protocols used by the devices. The hub module of the bus analyzes commands to discover and connect devices. The task bus and data bus provide other functions, such as transferring files and messages between devices.

Several preconditions have to be met before an intelligent vehicle and IoT devices can work synchronously to offer an interactive experience. In terms of design logic, it is important that interactive experience of the intelligent cockpit be consistent with that of mobile phones or other such devices. Regarding operating logic, intelligent cockpit applications must provide the unified functions of smartphone applications, and may be designed based on the hardware capabilities of cockpit peripherals. In addition, users want a seamless experience when they switch between cockpit and smartphone applications, especially when it comes to their calendar, navigation, music, video, and conferencing applications.

Ultra-fast connectivity technology for smartphones and head units will be able to help quickly converge the hardware resources, system capabilities, and service ecosystems of phones and vehicles, so that carmakers will be able to leverage the computing power of smart devices (e.g., smartphones) and the services of the mobile Internet ecosystem. The distributed platform for devices will link transit and other scenarios (e.g., office and home) to offer users the best possible experiences across devices and create an intelligent cockpit service system for universal scenarios.

In-vehicle optical applications: Lighting up a new vision for drivers and passengers

Viewing: Panoramic, immersive holograms for eye-opening experiences

Humanity's desire for superior visual experiences knows no limits. As vehicles become more intelligent, their front windshields, side windows, and panoramic sunroofs are quickly becoming displays that can show information through

lifelike holograms. As laser and pixel technologies continue to evolve, they are expanding the roles of headlights, from being mere sources of lighting to projecting 3D information in all directions around the vehicle.

In-vehicle optical applications are designed to create superior visual experiences as they support information display, interaction, and entertainment. In terms of navigation, the windshield can be used to enhance driving safety by displaying essential information and safety warnings like road directions and obstacles. The windshield and even rear side windows can be used for entertainment, serving as holographic screens that offer the kind of immersive 2K/4K viewing experiences that you get at the cinema. Curved panoramic sunroofs can project customized light patterns, to mimic everything from meteor showers and constellations to deep-sea coral reefs. Going forward, intelligent vehicles will also be equipped with headlights capable of wide-gamut, high-pixel projection that will allow users to project and watch movies outdoors.

Vehicles are quickly becoming the third living space for people after their home and workplace. This is why user demand for visual experiences on the go has been increasing. Users expect immersive experiences that deliver images and video with higher resolution and broader view. Users are also looking for new eye-friendly technologies that can help with carsickness. This means interactive functions not only have to create truly immersive experiences, but also help users avoid getting carsick while making long video calls or watching movies. In addition, rear-seat passengers expect optical display technologies to deliver a wide array of entertainment functions without fatiguing their eyes.

Looking to the future, spatial optical technologies – in tandem with human-focused experiences – will reproduce the real world with extremely high-resolution images that are sharper than even the human eye can process. This will require:

- **Wide-view, immersive technology:** Spatial optical technologies like freeform mirrors, diffractive optical waveguides, and polarization beam splitting can be used to project images up to 100 inches in size from a 10-inch display. With directed light field technology, users can watch 3D movies on in-vehicle displays without 3D glasses. Also, directed sound field technology offers amazing acoustics that would previously have been available only to best seats of an IMAX cinema.

- **True-color UHD displays:** Displays will soon come fitted with optical engines for 2K, 4K, and 8K video, and diffuser film displays

based on a micro-nano structure. These UHD displays will significantly enhance pixels and brightness, making the text and images they display so crisp that the pixels will not be visible to the naked eye. With RGB lasers, UHD displays will support DCI-P3 color space or even BT.2020 color space for 8K video, perfectly showcasing the true colors of objects being displayed.

- **Visual health:** Virtual imaging systems can display images at a 3-meter distance from the viewer's eyes, thus eliminating the risk of myopia. Passive cool tint technologies also make it possible for displays to emit zero radiation and reduce the amount of blue light that reaches the eye.

- **Human-focused experiences:** Carsickness is caused by conflicting information the human body receives from eyes and ears when a vehicle is in motion. Staring at an on-board screen in a moving vehicle often exacerbates this problem. When engineering technologies that focus on dynamic human factors are incorporated into on-board screens, this problem can be minimized or avoided completely. Eye fatigue occurs when the eyes' ciliary muscles contract too tightly. The technologies that enable eye tracking, vision screening, and diffuser film displays that automatically adjust the distance between your eyes and the images being projected can all help relax ciliary muscles.

Sensing: Intelligent all-around protection in all weather conditions for greater driving safety

Advances in the field of in-vehicle optical technology will make environment modeling more detailed and comprehensive. Innovative applications like near infrared sensing, thermal optical sensing, and image optical sensing will support more precise environment modeling, enabling drivers to see the invisible. Based on modeling, external environment information collected by sensors will make driving safer and more intelligent while meeting the service needs of drivers and passengers. Sensor-powered headlights can provide accurate information about low-visibility environments (such as when it's rainy, snowy, foggy, or nighttime) to alert drivers to blind spots. When data collected by sensors operating on different frequency bands is pooled together, useful insights can be extracted and used to identify biological factors and risks more accurately than ever before.

As more people tend to spend more time in their vehicles, it is crucial that intelligent vehicles of the future can support potentially life-saving safety functions, such as the ability to monitor the status of drivers, passengers, and the vehicle itself. Light sensing technologies like in-vehicle infrared and optical sensors can be used to promptly detect things like respiratory problems, an irregular pulse, and heart issues, and give timely alerts. These technologies can also identify driver fatigue and issue heads-up alerts to reduce the chance of human errors and accidents. They can even be used to detect whether children or pets are left locked inside a vehicle and automatically trigger solutions.

In the future, optical technologies that operate on different frequency bands will work with image recognition and processing technologies to bring intelligent vision to vehicles, ensuring all-round safety in all weather conditions.

- **All weather conditions:** All objects with temperatures above absolute zero emit infrared radiation over the 8–14 μm waveband. Infrared imaging technology can convert that infrared radiation into a visible picture, helping remove glare and identifying objects in rain, fog, or even total darkness. Conventional imaging technology that works on the 400–700 nm waveband (a waveband that is visible to human eyes) do not currently work in exceedingly dark, rainy, or foggy conditions.

- **All-round protection:** When an object vibrates, the frequency of the light signals it emits changes. Optical Doppler spectrum technology can capture micro-vibrations on a user's skin. Therefore, when combined with infrared thermal imaging technology, optical Doppler spectrum technology can be used to monitor a user's vital signs, including heart rate, respiration, and body temperature. This means the vehicle can issue alerts when the driver is becoming fatigued or if someone in the vehicle needs medical assistance.

Connecting: New interaction methods ensure better driving safety and stronger emotional bonds

In-vehicle optical applications provide new ways for vehicles to interact with their users and the world around them. These applications are also crucial for driving safety. Inside vehicles, augmented-reality head-up displays (AR-HUDs) are an intuitive tool for vehicle-driver interaction. They can directly display information on the windshield, enabling the driver to more easily view information, instead of having to look down at various instruments. The AR-HUDs can display real-time information, such as AR navigation directions, alerts for obstacles, vision augmentation in rain, fog, and darkness, as well as information about nearby gas stations and other services.

Intelligent lighting systems also provide a new way for vehicles to interact with the outside world beyond just their horn and signal lights. When a vehicle is in motion, intelligent lighting can project interactive information onto the road, such as vehicle width, alerts for rain and fog, and night vision, to help drivers make more informed decisions and enhance safety. In addition, intelligent lights can project useful information for pedestrians, such as turn and right-of-way signals. Intelligent lights are also capable of projecting emotions, showing customized information such as patterns, emojis, texts, and weather data, and can even enable other forms of interaction through light shows and concerts.

In the future, a variety of in-vehicle optical applications will create even more ways for intelligent vehicles to interact with people. This can happen through:

- **HUDs:** Currently, AR-HUDs use megapixel-level optical modulation engines and spatial optical technology, but future adoption of dual-focal plane technologies will pave the way for even more advanced multi-layer AR-HUDs that will be able to project dashboard information two to three meters in front of the driver, and navigation and other useful information seven to ten meters in front of the driver. Future naked-eye 3D technology

will also further improve the interactivity and experience of HUDs.

- **Lights:** With megapixel-level modules and optical lens, automotive lights will be transformed into projectors, displaying information such as vehicle-to-vehicle distance alerts and animated greetings. Vehicles that use precision laser lighting and sensing technologies will be able to interact with the environment through methods like dynamic ground projection (dubbed "dynamic light carpets"), to illuminate the surrounding area outside the vehicle and provide centimeter-level precision lighting. This will undoubtedly make driving safer and more fun. In the future, current/voltage modulation will also make it possible to display information in beams, and visible light communications technology will be able to support vehicle-to-vehicle communications.

- **Windows as displays:** Ultraviolet light projectors and fluorescent film glass will turn vehicle windows into colorful, full-size displays where notifications of the driver's intent, ads, and other types of information can be shown to pedestrians.

Intelligent vehicle-cloud services: Helping carmakers become digital, service-oriented companies

In the era of intelligent connectivity, we need smart vehicles, intelligent roads, and also an intelligent cloud. This cloud needs to enable data-driven closed-loop iteration of intelligent driving algorithms and effectively connect people, vehicles, and roads. It will also enable a variety of intelligent connectivity applications, such as intelligent cockpits, intelligent mobility power, intelligent driving, and intelligent transportation. Intelligent vehicle cloud services will be deeply integrated with capabilities at the application layer and become more agile to adapt to a fast changing market. With their leading innovation capabilities, vehicle cloud service providers will establish their unique competitive strengths in the market and help carmakers become digital, service-oriented companies.

Closed-loop management of intelligent driving data on the cloud for faster development and continuous iteration of algorithms

To solve the long-tail problem with intelligent driving, intelligent driving developers need to continuously enrich corner case datasets and simulation scenario libraries for iteration of intelligent driving algorithms. During this process, they need petabytes of data and a huge amount of computing power (more than 1,000 GPUs) for algorithm training, and must simulate driving astronomical distances (as far as 10 billion miles) to validate an algorithm. In addition to large storage capacity and computing power, the iteration of algorithms also requires reliable, secure, and scalable infrastructure services. The conventional model for data center construction puts the costs and O&M responsibility on intelligent driving developers, so we expect that cloud computing technologies will be widely applied in intelligent driving to address these challenges.

Cloud service providers will need to be capable of providing one-stop services on the cloud as this can help address the complex engineering problems of intelligent driving, like data collection, data replay, automatic labeling, identification of corner cases, incremental dataset generation, model management, training task management, model delivery, simulation scenario library building, simulation test, and algorithm adaptation. These tasks often account for more than 70% of the development workload. Therefore, intelligent driving algorithm development should be data-centric, and during this process, data should be decoupled from algorithms. This will help build an open enablement platform that provides a complete and automated development toolchain. Carmakers and developers will then be able to quickly build up their intelligent driving development capabilities, address the engineering complexity in algorithm development, lower technical barriers to entry, and allow for faster algorithm development and iteration. Specifically, intelligent driving developers need to:

(1) Provide scalable, secure, and compliant infrastructure for intelligent driving algorithm development

Hyperscale data storage and computing centers, built based on cloud platforms, can provide the massive uploading capacity, compliant storage services, and massive computing resources needed to handle the massive amounts of data that will soon be generated by intelligent vehicles. Carmakers developing algorithms for intelligent driving will be able to access affordable, scalable, reliable, and secure infrastructure.

(2) Address engineering incoherence and support the DevOps of intelligent driving algorithms

There are two major issues that hinder intelligent driving algorithm development: fragmented toolchains and lack of coherence in the development process. Cloud service providers must develop the ability to provide full-lifecycle services on the cloud, covering everything from algorithm development and testing, to commercialization and optimization. These capabilities should include a complete development toolchain, preset algorithms, and datasets and scenario libraries that are continuously updated, simulation, and validation. Support should be provided for user-defined algorithmic models and heterogeneous hardware. Cloud-based infrastructure and AI capabilities can help ensure a closed-loop intelligent driving development process, from data collection and processing, and identification of scenarios (especially corner cases), to algorithm management, training, simulation, and validation. These capabilities can help carmakers' intelligent driving R&D teams quickly locate problems, optimize algorithms, and conduct testing and validation, allowing for faster algorithm development and iteration.

New cloud-based simulation technologies to accelerate validation and iteration of autonomous driving algorithms

Cloud-based simulation can speed up the testing and validation of intelligent driving. Specifically, intelligent driving developers need to:

1) Recreate a virtual version of real-world scenarios to quickly build a simulation scenario library. The developers can use data collected by

vehicle-mounted sensors, HD maps, and publicly available simulation tools, to simulate complex, real-world road test scenarios on the cloud and quickly simulate complex traffic flows. This whole process will take only a few minutes.

2) Support the validation of multi-vehicle collaboration. Intelligent driving developers need to improve their abilities to validate different intelligent driving algorithms in multi-vehicle collaboration and vehicle-road collaboration scenarios.

3) Play out scenarios devised in a virtual cloud environment on real vehicles on empty roads to better validate algorithms. This can boost efficiency and safety while also providing true-to-life test scenarios.

4) Improve the efficiency of cloud-based parallel simulation. Intelligent driving developers can use container technologies and the resources available on the cloud for large-scale parallel simulation. In a single day, tens of millions of kilometers of driving can be simulated, shortening the algorithm iteration cycle from weeks – or even months – to just days.

HD maps are essential for simulation, whether in a virtual environment that simulates the real world, or a hybrid of virtual and real-world scenarios. Cloud service providers can build their HD map service capabilities in the form of cloud services while ensuring regulatory compliance during data storage and application. They also need to provide detailed coverage, unified standards, layered services, and dynamic updates, in order to support a wide variety of applications, including positioning applications, intelligent driving simulation/operations, intelligent and connected industry parks, intelligent driving, and smart cities.

Vehicle cloud service providers need to provide map data storage and application services based on secure and compliant dedicated cloud infrastructure while meeting applicable regulatory requirements. Leveraging the large storage capacity of cloud, abundant computing resources, and intelligent algorithms, the providers can process road test data in a secure and compliant manner and support third-party partners in intelligent driving development and map data application services.

Huawei hopes to form an alliance of HD map service providers to create greater synergy across the industry. Huawei's HD map cloud services support data access by other map service providers. Following an intelligent inspection of data quality and post-processing, Huawei can establish unified service standards and integrate resources from other map service providers. This helps reduce redundancy in map drawing work and cut costs. Through open and flexible operations, Huawei can provide users with HD map data services that are responsive, up-to-date, and all-encompassing.

Cloud-edge-device collaboration can help dynamically distribute HD map data and update maps through crowdsourcing. With cloud-edge-device collaboration, HD map data can be distributed on demand and flexibly used, facilitating intelligent driving and smart city applications. In addition, collaboration between the cloud and intelligent connected vehicles, other traffic participants, roadside infrastructure, and roadside edge computing helps update the dynamic layers of HD maps in real time, while crowdsourcing enables the update of static layers, helping keep HD maps up-to-date.

A unified data service system to enable carmakers to become digital, service-oriented companies

As ICT technologies are increasingly integrated into the automotive industry, cloud computing is allowing intelligent connected vehicles to provide new functions and experiences. Carmakers rely on cloud-based intelligence to build scenario-specific big data application service capabilities. This is because they need to integrate their underlying business logic with big data and AI when developing applications and services based on their vehicle data. For example, early warnings of battery thermal runaway require a combination of knowledge and technology in both the electrochemical and AI fields. As intelligent connectivity scenarios are further segmented, carmakers need to build a unified data application service system and remain open to collaboration to meet the massive service demand.

Application-centric intelligent vehicle cloud services, built based on the Cloud-native 2.0 architecture, can help carmakers build a unified and complete data service system covering collection, storage, consolidation, computing, management, and services. This system should enable closed-loop data management and continuous iteration of applications. Carmakers can also work with third parties in various domains to provide intelligent applications and services that meet personalized consumer needs, and become digital, service-oriented companies.

1) Full data collection and aggregation based on cloud-native infrastructure

Cloud service providers need to build unified, efficient, and application-centric data service platforms with diverse computing capabilities and a high level of coordination between software and hardware. Such a platform should be able to manage and support heterogeneous hardware, and shield applications from the complexities of the hardware. With open and standardized connected vehicle technologies, cloud service providers will be able to connect massive numbers of vehicles and provide millions of concurrent services on the cloud. This will help build up data channels, and collect and aggregate data from components such as intelligent mobility power, intelligent driving, intelligent cockpits, and intelligent connectivity systems. This will help build a full data lake for intelligent connected vehicles on the cloud and support the creation of digital twins of vehicles.

2) Data value mining and application innovation based on cloud-native intelligent services

There are two key preconditions for enabling intelligent services: The first is the building of full-lifecycle data management capabilities on the cloud, from data collection, transmission, and storage, to labeling, analysis, and application, in order to reduce data governance costs and fully unlock the value of data. The second is the development of a converged data analytics platform with cloud-native technology, which helps transcend data boundaries and enable efficient cross-source and cross-domain collaborative analytics.

As the AI technology and ecosystem on the cloud mature, cloud platforms will continue to enrich algorithm libraries and provide capabilities like automatic labeling and preset algorithms to lower the technical barriers to entry for AI application development. The hyperscale computing power and massive amounts of data available on the cloud can enable data value mining and the innovation of intelligent big data applications. This will then enable the development of intelligent applications like intelligent diagnosis of core vehicle components, vehicle status monitoring, vehicle function preference analysis, and analysis of component working conditions. The data obtained from these applications and services can also help optimize product design and R&D.

3) Build a thriving service ecosystem based on agile and open application development capabilities

Cloud service providers can use cloud-native and microservice technologies to split applications into microservices that can be independently deployed and run. Such high scalability enables applications to have higher availability. It will also be necessary to move from the traditional model, in which application development and delivery are separate, to the integrated DevOps model, as this can speed up application development and iteration.

Cloud service providers can also open up their data service capabilities to enable third-party development of intelligent applications and help carmakers build an ecosystem of applications essential to our everyday lives. This will allow companies to offer data as a service, thereby unlocking the value of data more rapidly. Carmakers and their partners can provide users with rich personalized services and applications, develop new use cases and business models, and explore services as a new source of revenue.

Intelligent mobility power: High convergence, high efficiency, and high voltage

A highly converged and simplified power system with a self-evolving, AI-enabled structure

The development of conventional power system architectures is a lengthy and costly process. With the electrification of more vehicles, more electric vehicle (EV) components need to be integrated to simplify development, adaptation, layout, and evolution.

Most of EV power systems currently in use are three-in-one units that integrate motor control units, motors, and reducers, which, in essence, is an integration of functions and hardware. The EV power system of the future will be a six-in-one unit that integrates the three-in-one electric drive system and the three-in-one on-board charging system. Compared with the traditional separated model, a converged model would be 30% smaller and 20% lighter. A six-in-one unit can be flexibly adapted to simplified vehicle layouts, and its higher level of integration would mean that carmakers can cut spending on component testing and introduction and effectively slash development costs.

Developing a converged power system requires the convergence of multiple components by integrating electric systems, boards, chips, algorithms, and control units. A hyper-converged system would also need higher-level EMC to eliminate any interference that the convergence process may cause. In addition, a more efficient heat dissipation system would be necessary to meet the increased cooling needs of such units. More converged control functions for power systems will also need an architecture shared by in-house AUTOSAR Classic Platform (CP) and the AUTOSAR Adaptive Platform (AP) that supports a domain-oriented control evolution.

Hyper-converged power systems can enable multiple system-level value-added features and satisfy the development requirements of any on-demand functions, such as OTA-enhanced power devices, rapid in-vehicle software upgrades, driving modes updates, continuous optimization of noise, vibration, and harshness (NVH), and wider performance boundaries. All of these would improve the performance of the EV power system over the whole lifespan of a vehicle.

The convergence of multiple control units provides EV power systems with a unified platform that can upgrade intelligently. Iterative component features can be scheduled more efficiently using an AI platform, thereby meeting more complex and intelligent power needs effortlessly.

Thanks to AI, EV power systems will be able to learn, iterate, and evolve on their own. This will be seen in applications such as:

(1) Proactive safety warnings that can be provided one week advance to warn of potential battery thermal runaways, and cloud-based intelligent remote calibration that can enable an EV power system to perform better over the entire lifespan of the vehicle.

(2) Visible, controllable, and predictable EV power system quality that is available throughout the vehicle's entire lifecycle.

(3) AI-enabled EV power system service life predictions that can extend the system's lifetime by avoiding scenarios and operating conditions that could affect service life.

(4) On-demand maintenance or even completely eliminated maintenance, shifting away from the current maintenance paradigm based on mileage and driving hours to greatly improve customer satisfaction.

Bits managing watts: AI-powered optimization maximizes energy efficiency at three levels

Thanks to digital technologies like 5G, AI, big data, and IoT, EV power systems can use "bits managing watts" to create synergies between electric, thermal, and kinetic energy. Simultaneously, an internal AI system can be used to optimize energy efficiency in all working conditions. This would allow the electricity stored in EV batteries to be fully converted into power, helping alleviate range anxiety and offer better travel experiences. Future electric vehicles will need to be efficient at three different levels: the component level, the system level, and the vehicle level.

First, components can be made more efficient through leveraging insulated gate bipolar transistors (IGBTs), silicon carbide (SiC) components, and gallium nitride (GaN) components. Advanced packaging technology can also be used to improve cooling systems, reduce parasitic parameters, and improve the electrical robustness and reliability of power modules. This will make even high-voltage, high-temperature, and high-speed operations more efficient.

Second, systems can be made more efficient by leaning harder into the convergence trend and making EV power systems a coupling component that integrates the mechanical, electrical, and thermal fields, among others. A digital and intelligent development platform can be used for multi-objective and multi-parameter optimization, circuit topology improvement, and algorithm control. Moreover, AI and big data technologies will further improve virtual testing and remote online calibration. Each subsystem within an EV power systems will then convert power more efficiently, increasing the overall efficiency of the complete EV power systems.

Third, vehicles as a whole can be made more efficient by digitally connecting their different system components that are currently separate, including the electric drive, thermal management, steering, and braking systems. This will allow the different components to complement each other in terms of energy efficiency. In addition, bits must be used to manage watts. This can help better coordinate electric, kinetic, and thermal energy, effectively reduce energy loss in non-power systems, and increase energy supply efficiency. For example, excessive heat from the motor can be used to preheat batteries in the winter, eliminating the need for a separate positive temperature coefficient (PTC) heater. The on-board charger (OBC) and the air conditioner compressor can share a high-voltage topology to maximize the utilization of power devices.
In the future, with the support of cloud and AI, vehicle energy consumption management will become more intelligent. Ultimately, optimal energy consumption management policies will be created for the same vehicle in different scenarios and working conditions.

1000 V power systems and 5-minute fast charging

The electric vehicle industry is developing rapidly as consumers become more accepting of electric vehicles. However, charging convenience, battery life, and safety remain the three major concerns that put consumers off from going electric. Among these three problems, charging convenience receives most attention.

If the charging time for a 100 kWh battery pack can be cut from 50 minutes to less than 5 minutes, we would need to increase the charging power of each charging gun from 60 kW to 500 kW. To achieve fast charging under the same power conditions, high-voltage power systems are needed as they can effectively solve the problems that low-voltage systems face, like excessive charging current, high charging facility costs, heat dissipation difficulties, and safety considerations.

The technologies required to create such high-voltage power systems are basically ready for use. One interesting example is the new generation of power semiconductor technologies based on SiC. The critical breakdown field strength of SiC-based power devices is nearly 10 times that of those made using pure silicon, which means that SiC-based devices can easily operate at higher voltages. SiC-based devices of 1500 V or above are already ready for mass production and can be used to develop high-voltage platforms for new-energy vehicles. In addition, the low on-state resistance and the high thermal conductivity of SiC-based devices can boost system efficiency. The development and application of SiC materials provides a solid foundation for the evolution of EV power systems from low-voltage systems to high-voltage systems. High-voltage vehicle components like OBCs, battery management systems (BMSs), and powertrains are also already ready for mass production.

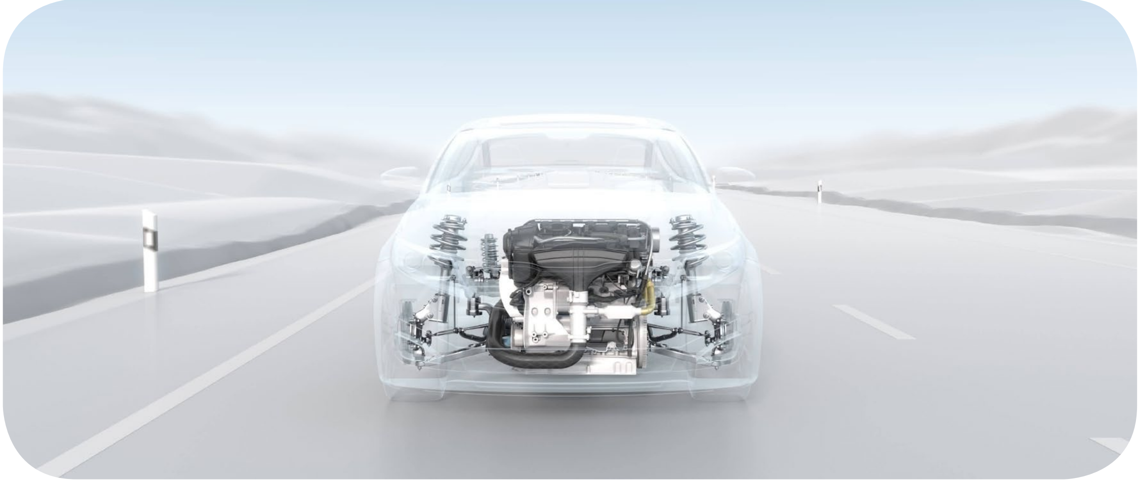
The voltage plateau of EV power systems will further increase from 800 V to 1000 V, charging currents will increase from 250 A to 600 A, and charge rates will rise from 2C to 6C. In addition, the time for the state of charge (SOC) from 30% to 80% will be cut from 15 minutes to 5 minutes. As the voltage of SiC-based power devices continues to increase, EV power systems with higher operating voltages will come more common in the market.

Safety and trustworthiness: Defense in depth through cyber security and functional safety integration

Today's vehicles are increasingly electric, connected, and intelligent, and have complex and integrated E/E systems. The safety of the new functions that come with these new developments is now often a matter of system safety engineering. Finding ways to protect against external attacks, cope with unforeseeable faults and diverse environmental conditions, and ensure safe and reliable mobility has become a common challenge facing the industry. As we embrace intelligent connected vehicles, the notion of vehicle safety and security is also changing. For intelligent connected vehicles, and intelligent driving systems in particular, there are three key aspects to safety and security – functional safety; safety of the intended functionality (SOTIF); and cyber security, data security, and privacy protection.

Functional safety: High-standard safety and reliability in all scenarios and all weather conditions

By 2030, the importance of functional safety will have become more salient with the widespread use of technologies such as intelligent driving, chassis-by-wire, high-bandwidth communications, wireless networking, regional access, SOA design, and central computing and control. In addition, enormous challenges are anticipated for traditional functional safety in terms of security



design and continuous iteration of super software platforms, AI algorithm security, situational awareness and security planning and control in all scenarios and all weather conditions, and security design and verification of fail-operational vehicle E/E systems. However, with continuous improvements in advanced materials, manufacturing processes, architecture designs, as well as multi-level redundancy through the chip, circuit, board, and system, along with a minimum safety system design, intelligent vehicles of the future will meet or even exceed the safety requirements of Automotive Safety Integrity Level (ASIL) D. This means they will be able to function with guaranteed levels of stability and reliability in any scenario and under any weather conditions.

At the architecture and system level, heterogeneous backup of domain controllers will become the standard configuration to address system failure and random hardware failure. This will help ensure mini driving control systems and mini driving functions such as driving, braking, steering, gear shifting, mandatory lighting, critical speed control, gear indication, having at least one door that can be opened, and mandatory end-outline marker lamps. It will also help ensure that emergency processing mechanisms, such as communications and power supply redundancies, are in place for key signals and systems. Vehicles with highly automated systems or more advanced systems must support redundant heterogeneous systems that have the necessary environmental awareness capabilities.

To make this happen, the following technical measures are required:

(1) A fail-operational design for the central computing platform. The central computing platform is a core component, and in order to meet safety requirements, its key hardware, software, and system architecture must be built with a fail operational design:

Reliable architecture: This requires a multi-layer fault monitoring and handling framework; virtual hardware security partitioning and heterogeneous software deployment; redundancy designs for power clocks, communications links, and redundant vehicle controls; and fault cross-check interlocking mechanisms. These measures will help completely resolve common cause failures and cascading failures. In addition, the minimum safety system design helps ensure 100% safety and trustworthiness.

Automotive-grade engineering: Highly-conductive materials, phase change materials, and new liquid cooling technologies can be harnessed to achieve efficient heat dissipation at the chip, component, board, and system levels. High-voltage, high-current switch technology and high-speed cable technology can be used to reduce the bit error rates of high-speed signal transmission. Electromagnetic interference suppression, high-reliability small-scale surge protection, and power management technologies can help improve systems' EMC. Additional advanced processes can also help extend service life and meet safety requirements beyond ASIL D. These processes include design for assembly, vehicular adhesive dispensing, coating, gluing, pipe corrosion and condensation test limits, optical coating, and soldering.

Maintenance-free across the full service life: Based on chip, software, and system failure model libraries, proactive maintenance is performed automatically in real time to predict, prevent, and mitigate 0 km failures.

(2) Architecture-level redundant safety:

Input/Output (I/O) device abstraction and SOA-based security design and FFI design for proximity sensors and actuators; secure, redundant access of important I/O devices and distributed, secure deployment of critical services; real-time status monitoring and fail-safe management for SOA-based service platforms; minimum safety system design; high-level safety with significantly better vehicle availability and user experience

Model-based systems engineering (MBSE) and model-based safety analysis (MBSA) integration:

- Integrated model design, analysis, and verification of system design, functional safety, and execution models;
- Adaptive, safe hierarchical architecture and high cohesion, low coupling of modular components;
- Paced iteration of vehicle software and fast functional safety design, analysis, and verification.

Architecture-level functional safety simulation and verification:

- Vehicle functional safety simulation: Hazard scenario library, fault database, vehicle architecture platform model, simulated external interfaces, vehicle model, driver behavior, fault response model, and operating environment model;
- (Semi-) autonomous functional safety verification;
- Closed-loop functional safety of vehicles as a whole.

(3) Double-guaranteed communications security: This requires a security design with end-to-end communications security, real-time monitoring of network faults, data flow rerouting in the event of network failures, and dual-fed and selective receiving. This helps ensure reliable degradation and safe operations in the event of a network fault. The wake-up function, power supply, and the links of the external sensing input, vehicle control information input, and key actuator output must be redundant.

SOTIF: Turning "unknown hazardous" scenarios into "known not hazardous" scenarios

When fully autonomous driving becomes a reality, the responsibility for driving safety will shift from the driver to the vehicle. Unlike functional safety, SOTIF is mainly about preventing and addressing unreasonable risks caused by functional insufficiencies and reasonable foreseeable misuses, including those caused by inadequate consideration of target scenarios, and diverse environmental factors that may affect sensor performance. Beyond those, SOTIF also needs to constantly explore "unknown hazardous" scenarios and turn them into "known not hazardous" scenarios. SOTIF will be one of the key issues to be addressed before intelligent driving can be fully commercialized.

As intelligent driving functions become more widespread, SOTIF-related issues will be increasingly prominent. The following points are particularly important:

(1) The development of SOTIF standards in all key markets should be closely monitored. These standards must be fully implemented at all stages from system design and specification to verification, validation, and field monitoring. This is key to ensuring end-to-end SOTIF.

(2) Research is needed for SOTIF-related risk analysis and response. This can be done from multiple aspects such as compliance with traffic regulations, determination of operational design domain boundaries, dynamic driving task execution, minimal risk manoeuvre, human-machine interaction, and response to foreseeable scenarios.

(3) Traffic regulations should be digitalized so that they can be understood and followed by autonomous vehicles, allowing them to easily integrate into the larger transportation system.

(4) It is essential to have a safety time domain design that comprehensively considers the total time needed for autonomous vehicles to sense, plan, and act, and maintain a proper time margin. This will help cope with uncertainties, including uncertainties caused by other traffic participants' actions, to guarantee safety on the road.

(5) Sufficient simulation, testing on a closed test track, and road tests are needed, along with enhanced audits and assessments, in order to fully explore potential functional insufficiencies and triggers that can led to hazardous behavior.

(6) During the vehicle operation phase, data analytics and predictive functions should be used to promptly identify potential hazards caused by evolutions in the environment and driving habits, and appropriate measures need to be taken accordingly. Ultimately, the intelligent driving systems should reach a safety level comparable to an excellent human driver, in order to meet user expectations for the safety of autonomous vehicles.

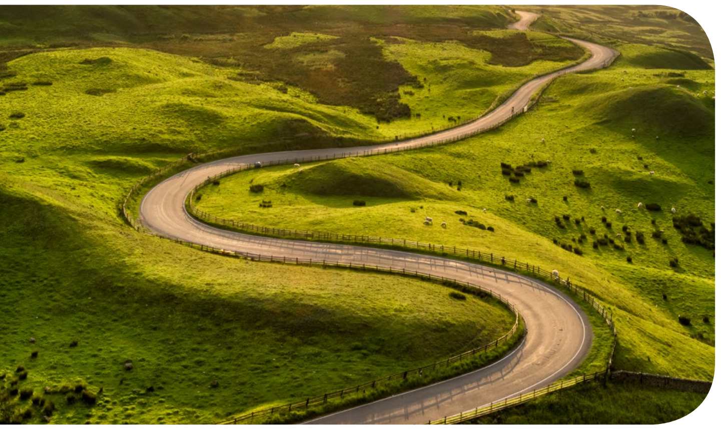
Cyber security, data security, and privacy protection for a comprehensive safety net

Typically when we talk about intelligent mobile devices, the focus is on the safety of the user. What sets intelligent vehicles apart is that designers must take into account the safety of people in and outside the vehicle. Strictly adhering to safety guidelines and ensuring the security of intelligent automotive products and services is a fundamental requirement for ensuring the safety of both people and property.

The automotive industry is embracing the CASE transition. This is expected to create many risks in new cyber security, data security, and privacy. Addressing these risks requires the joints efforts of all stakeholders, including regulators, carmakers, and component suppliers. They need to work together to build a full-lifecycle safety net for intelligent vehicles, in order to address cyber security challenges and ensure the safety and security of intelligent automotive products and services.

1) Cyber security

According to security consulting firm Upstream, in the period from 2011 to 2019, there were 342 attacks targeted at intelligent vehicles. The number of cyber attacks directed at intelligent vehicles has been rapidly increasing. The attack methods have evolved from traditional system hacking through physical contact to remote attacks that require no physical contact at all. Remote attacks account for more than 90% of all cyber incidents, and nearly one-third of them affect vehicle controls. In terms of the distribution of the attacks, the vehicle cloud is the most frequent target, accounting for more than 20% of all attacks. The vehicle cloud, key, and on-board diagnostics (OBD) system interfaces are the points most vulnerable to attack. There's also an emerging type of attack that targets a



vehicle's sensors. In the future, 24/7 connectivity will be a prerequisite for continuous functioning and updating of intelligent vehicles. More and more peripherals and network interfaces will be deployed in the vehicles. Always-online vehicles mean more attack surfaces and more susceptibility to a wide range of attacks that come in different forms, and the consequences of these attacks could be serious.

The next generation of computing and communications architecture must be designed with the following considerations in mind:

(1) As logical functions are centralized in high-performance computing devices, the potential impact of an attack will become wider.

(2) The use of SOA-based services will create challenges related to critical service permission control and communication security.

(3) Open platforms will present persistent security risks for third-party software and hardware.

(4) In addition to conforming to laws and standards, intelligent vehicles of the future will also need to ensure the trustworthiness of both process and results.

The central computing platform is the last line of defense against attacks. The cyber security of the central computing platform needs to be approached from three major directions: platform security, in-vehicle security, and outside-vehicle security. The vehicle connects with the outside world mainly through sensors and network interfaces. Technical tools such as access authentication, intrusion detection and prevention, and AI security and attack defense are required to keep attackers out. Inside the vehicle, computing and control modules are the main targets of attacks. Access control, security isolation, security degradation, and diagnosis and recovery technologies can be used to ensure the system cannot be breached by hackers.

In short, cyber security involves a sophisticated attack-defense system and needs to be addressed on multiple fronts:

(1) Central computing platforms – the lifeline of intelligent vehicles – need to be protected through underlying designs of core technologies (e.g., chips, OSs, and encryption algorithms) and architecture; key technologies such as root of trust, encryption algorithms, trusted computing and OTA, and intrusion detection and isolation; better understanding, detection, and evaluation of AI uncertainty; and enhanced SOTIF-related capabilities.

(2) Carmakers need to work with tier-1 and tier-2 suppliers to build an in-depth defense system across the entire vehicle lifecycle to prevent remote control of vehicles by hackers, and avoid leakage of data stored locally or on the cloud.

(3) Intelligent vehicles need to be resilient. Cyber security and resilience measures should be put in place to allow a hacked system to continue providing stable vehicle control services, or isolate the hacked vehicle control services and perform deterministic degradation to let other unaffected vehicle control services continue to work effectively and safely.

Specifically, the safety of vehicles should be enhanced across their full lifecycle and from different aspects such as cyber security governance, customer requirements, architecture design, protection and defenses, anomaly detection, prompt responses, and fault recovery. In 2030 and beyond, the key technologies for vehicle safety and security will include AI-based on-board intrusion detection systems, third-party software supply chain security and runtime integrity protection, resilient architecture, intrusion tolerance, zero-trust-based continuous authentication and source tracing of third-party devices, and detection and defense of malicious signals from sensors. Resilient architecture and intrusion tolerance depend on the integration of cyber security and functional safety in both the design phase and runtime.

Design phase: In this phase, steps should be taken to prevent known attack types. For known attack types and failure modes, threat analysis and risk assessment (TARA) and hazard analysis and risk assessment (HARA) should be integrated, so as to support comprehensive cyber security and functional safety requirements and avoid direct conflict and overlaps

Runtime: Designers should assume that during runtime, hackers will sometimes be able to successfully breach the system. Based on the system mission, designers should further integrate security detection, functional safety and cyber security risk analysis, functional safety response, and the fixing of cyber security vulnerabilities, in order to prevent functional failures caused by cyber attacks.

2）Data security and privacy protection

Intelligent connected vehicles will exist in a complex connectivity environment consisting of people, vehicles, roads, clouds, and networks. Data is becoming an essential resource, which is not only driving the service innovation and development of intelligent connected vehicles, but is also making data an integral part of our everyday lives. As data security of intelligent connected vehicles becomes increasingly important, corresponding governance systems will be incrementally optimized in all aspects, from data security awareness and data environment security control to data O&M security control, data asset security control, and data application control. Intelligent connected vehicle manufacturers, suppliers, and service providers must all improve data security capabilities. This includes implementing technological protections (e.g., user authentication, data encryption, access control, application management, intelligent anonymization, and network protection), and building systemic data security and compliance throughout organizational and product development, transactions, business commitments, and services. Specifically, the following principles should be applied to the use of data: lawfulness, fairness, and transparency; purpose limitation; data minimization; accuracy; storage limitation; integrity and confidentiality; and availability.

Sensitive personal data should be centrally managed to ensure security. Full-lifecycle privacy protection measures that cover vehicle systems, cloud big data platforms, backend service platforms, and data processing by third parties must be put in place. There are three major technical measures that can make this happen:

(1) Intelligent in-vehicle processing: Sensitive personal data should not be sent to the cloud. Instead, intelligent functions, such as voice and facial recognition, should be realized in the vehicle.

(2) Data invisibility: Technologies such as homomorphic encryption and differential privacy can minimize the use of sensitive personal data.

(3) End-to-end privacy: Privacy protection should be integrated into and prioritized throughout the entire data lifecycle from personal data collection and use to its retention, transmission, disclosure, and disposal, and the entire process should be transparent, well structured, strictly controlled, and traceable.

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