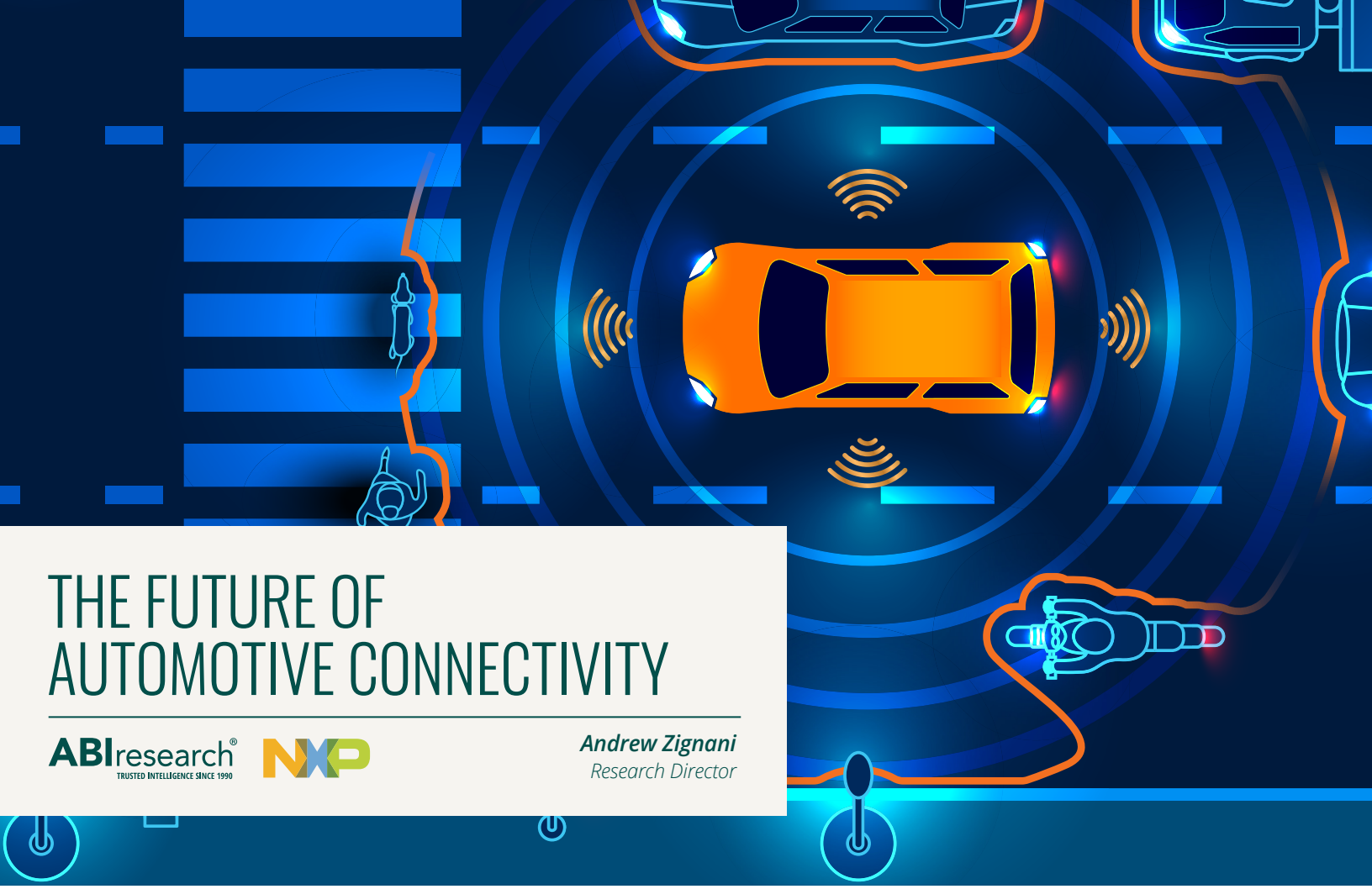

THE FUTURE OF AUTOMOTIVE CONNECTIVITY

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INTRODUCTION

The automotive industry is experiencing an unprecedented transformation as it takes on the transition to electric, increasingly autonomous, and connected vehicles. Among these automotive megatrends, automotive connectivity stands at the forefront of vehicle design decisions, thanks to its central role in enabling a wide range of innovative user experiences, value-added services, safety and security enhancements, and new features that are changing the way drivers interact with their vehicles. To make these new dimensions possible, cars will need to support a number of wireless technologies, including high-performance Wi-Fi, Bluetooth, Ultra-Wideband (UWB), Near Field Communication (NFC), IEEE 802.11p (DSRC), and cellular connectivity, in order to enable key use cases, such as advanced in-car infotainment and audio systems, secure vehicle access and sharing, intelligent vehicle data collection, over-the-air (OTA) updates, vehicle diagnostics and health management, tire pressure monitoring systems, vehicle-as-hotspot, and Vehicle-to-Everything (V2X) communications functionality, among others.

This white paper will highlight the future of the connected car and discuss how key wireless connectivity technologies will help to enable new innovative use cases within and around the vehicle. Discussion will focus on short-range wireless technologies such as Wi-Fi 6, Bluetooth, UWB, NFC, RAIN RFID, V2X, as well as on cellular technologies. The paper highlights the need to support multiple connectivity technologies within the vehicle to effectively address the existing and emerging use cases and applications. The discussion will centre upon four major areas, including vehicle-to-cloud connectivity and telematics, in-vehicle experiences, smart access and shared mobility, and V2X. In addition, it will highlight how new vehicle architectures will be fundamental in ensuring that vehicles of the future will be able to provide secure, robust connectivity that can maximize vehicle performance, create new services and business models, and enhance vehicle features once deployed.

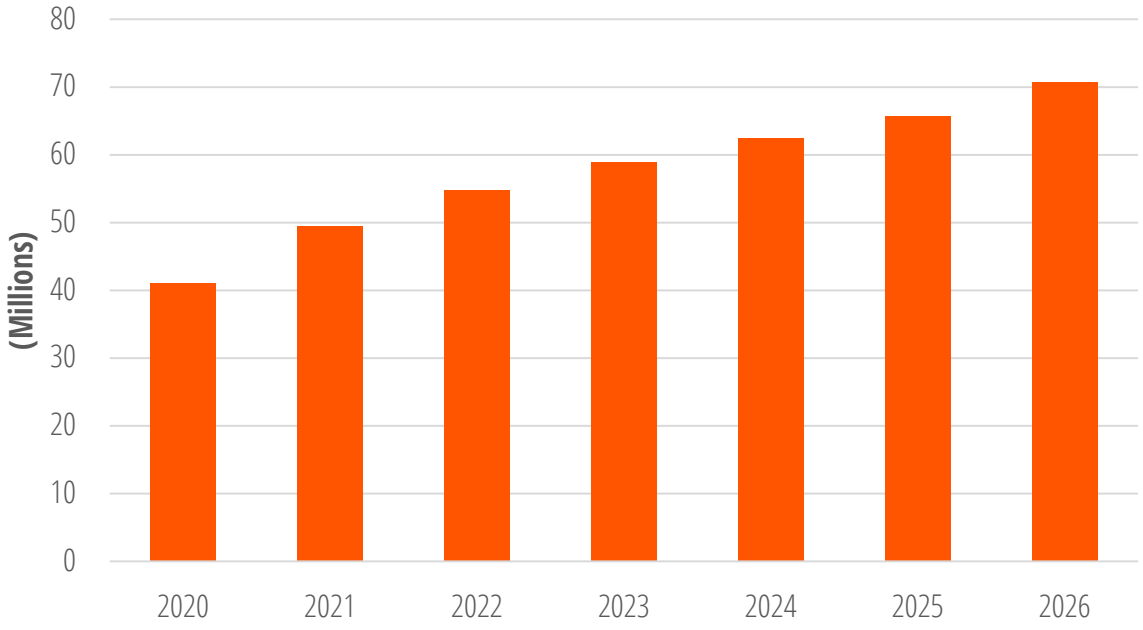
VEHICLE-TO-CLOUD CONNECTIVITY

The modern vehicle is evolving to become more electric, connected and increasingly autonomous. These enhancements are transforming vehicles into comprehensive IoT platforms, resulting in a shift away from hardware-centric devices of the past towards software defined vehicles that evolve over the course of their lifetimes to enable new features, provide greater security, enhance safety and efficiency, and create valuable new services and business models for consumers and OEMs alike. Recent advancements in computing, sensors, cloud platforms, and connectivity are enabling vehicles to evolve into rolling data platforms equipped with growing numbers of high-performance sensors. These have enabled more advanced safety systems and are building the path towards more automated vehicles. At the same time, end-user demands for better in-vehicle experiences regarding entertainment, comfort, and safety are leading to growing adoption of personalization via voice assistants, advanced digital cockpits with multiple displays, video streaming and gaming, and OTA updates, enabling new features within the realms of infotainment, autonomous driving, or comfort related functionalities. Unsurprisingly, this increasingly places vehicle-to-cloud connectivity at the forefront of vehicle design decisions.

As a result, both the number of connected vehicles and the amount of data being generated by vehicles is growing enormously. As Chart 1 demonstrates, by 2026, ABI Research forecasts that there will be over 70 million connected vehicles shipping annually, equating to 75% of all vehicles being shipped at that time. These vehicles will require high-speed, robust, Wi-Fi and cellular connectivity to the cloud in order to effectively transition to new software-defined and service-oriented approaches that can enable vehicles to quickly deploy new services and experiences while improving vehicle performance and intelligence over time.

Chart 1: Global Connected Car Shipments, 2020 to 2026

Source: ABI Research



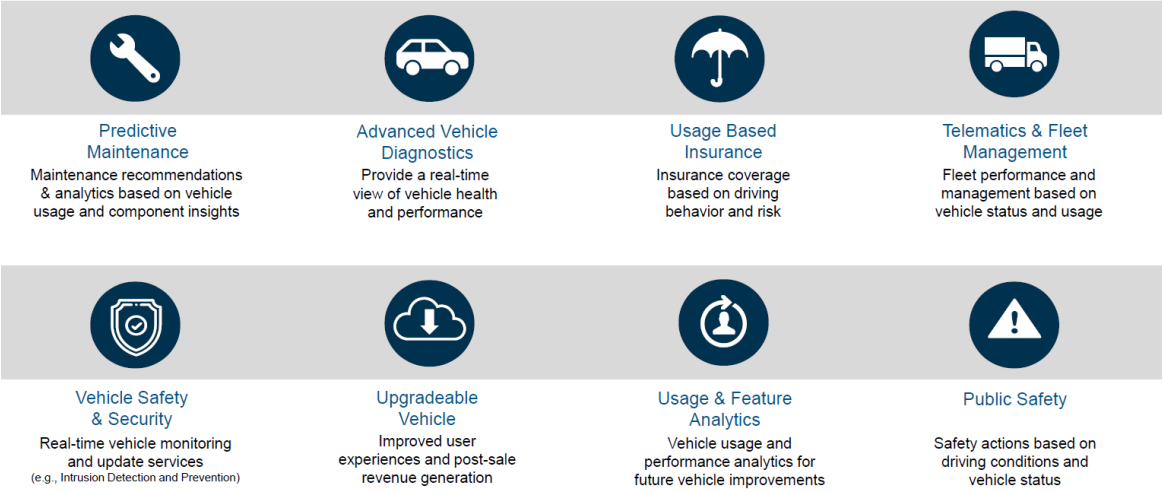
CONNECTED VEHICLE USE CASES

Wireless connectivity is becoming a key differentiator and more vital component of the vehicle purchase decision. While historically, automotive OEMs have used connected car features as a way to differentiate in a competitive market, carmakers now see the growing business opportunity to monetize this connection and use connectivity to generate revenue via OTA updates, lifecycle management, new software and experiences, and the transmission of data from millions of connected vehicles to create valuable new services. Unlocking big vehicle data is an enormous opportunity which is being enabled by multiple converging trends, including vehicle compute and central gateways, automotive Ethernet, cloud computing and storage, and high-speed wireless connectivity via 5G and Wi-Fi 6.

Figure 1 demonstrates some of the key connected vehicle use cases. While many connected vehicle use cases have historically focused on information sharing applications such as emergency calling, entertainment, and location-based services, there are growing activities in more advanced analytics and machine learning applications that will leverage the huge amounts of data generated by up to hundreds of vehicle sensors. This will enable use cases such as predictive maintenance, advanced vehicle diagnostics, performance and efficiency improvements, and feature expansions. As a result, vehicle manufacturers will be able to swiftly deploy new vehicle services, user experiences, and vehicle improvements, leading to additional revenue generation and closer relationships with customers throughout the vehicle's lifecycle.

Figure 1: Connected Vehicle Use Cases

Source: NXP



Today's vehicles are typically unable to adapt over time or provide new capabilities after the car is purchased. However, there is a strong interest among OEMs to enable an infrastructure where new features and services can be rapidly deployed. OTA updates are rapidly taking hold within the automotive market, with the Return on Investment (ROI) justified easily by the ability to generate revenue with new features and to correct software errors and apply cybersecurity patches without the need to physically service vehicles, improving the user experience and avoiding damage to brand reputations. As vehicle functions become increasingly software defined, the value proposition of OTA updates will grow over time. For example, OTA updates will deliver functional improvements to the vehicle after the POS (point of sale), making the vehicle upgradeable, a paradigm championed by Tesla and one that other OEMs also starting to explore and implement.

To enable these use cases, OEMs are increasingly adopting service-oriented gateways that support secure, vehicle-wide OTA updates that go beyond the capabilities of typical automotive microcontrollers. These gateways conduct operations outside of the traditionally risky infotainment realm, an area not known for secure OTA. For example, NXP's automotive-grade S32G processor has the performance and networking capabilities to rapidly deploy new use cases and enable upgradeable vehicles for global OEMs. This S32G family of processors are central to NXP's efforts in helping its partners monetize vehicle data, including its collaboration with Amazon Web Services (AWS) and its Vehicle edge-to-cloud compute solution which aims to enable new automotive industry revenue opportunities.

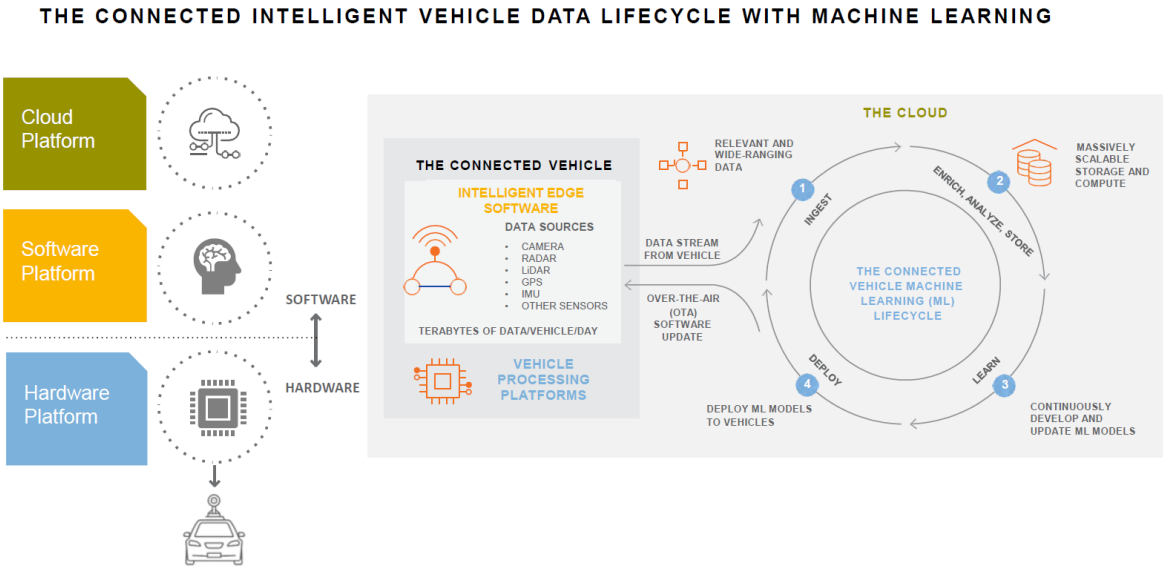
NXP's S32G also serves as a key component in NXP's collaboration with MOTER, an insurtech company that seeks to connect the insurance and automotive industries through a secure data platform, alongside the Fusion Project, an automotive industry collaboration aimed at defining a streamlined data lifecycle platform for connected vehicles.

These efforts at managing data are important as some industry estimates suggest that future autonomous vehicles will generate up to four terabytes of vehicle data each hour, while even modern vehicles today are esti-

mated to generate 25 gigabytes of data per hour, significantly dwarfing other connected car use cases such as audio and video streaming. But even before autonomous vehicles become ubiquitous, significant data is already being generated from ADAS systems with an increasing number of cameras, radars and other sensors, as well as from EV and battery systems that provide valuable insights. This data can be pre-processed within the vehicle and uploaded to the cloud for data analysis to improve algorithms and machine learning models. These models can then be deployed via OTA updates to the vehicle, resulting in more intelligent vehicles that become safer, more efficient, and more automated over time. Figure 2 highlights this evolution towards continual improvement via automotive data, machine learning improvements, and OTA updates over a vehicle's lifecycle.

Figure 2: The Connected Vehicle Continual Improvement Cycle

Source: NXP



For electric vehicles, this process can be leveraged to improve the efficiency of core functional vehicle capabilities. Electric vehicles are ramping rapidly and will account for nearly 30% of the annual car production by 2030, according to ABI Research. Increasing the efficiency of these vehicles will become critical in meeting consumers' range concerns (the top consideration for EV buyers). For example, torque selection can be optimized further by optimizing with knowledge of the trip, alongside taking advantage of contextual awareness via crowd sourced knowledge and local geographical knowledge combined with machine learning for behaviour recognition and more predictive control. Polestar recently made available a software update for the Polestar 2 that increased the peak charging rate alongside improvements in range due to tweaks in the regenerative braking system. Other features can also be optimized. For example, Volkswagen recently launched OTA updates for its ID3 electric hatchback, enabling improvements to lighting functions, improved surroundings recognition, infotainment upgrades, alongside other performance and stability enhancements. The company promises to deliver OTA updates to the ID family every 12 weeks.

THE TRANSITION TO MORE AUTONOMOUS VEHICLES

According to ABI Research, there is a consensus that the next wave of innovation and strongest revenue opportunities within autonomous driving will be within the L2+ segment. L2+ is particularly appealing to OEMs as it delivers self-assist capabilities without extraordinary risk exposure/liability and cost addition. Tier One suppliers are witnessing a higher number of OEM customers looking at all possibilities to enrich the feature set of L2 systems while maintaining it as a driver-assistance system with the driver-on-the-loop. Consequently, an increasing number of OEM's and automotive Tier1 suppliers, are developing advanced-driver-assistance system (ADAS) platforms with L2+ capabilities that can be further scaled across their vehicle fleets. Secure OTA updates are will be critical for the rollout of new functionalities in L2+ systems as they will not be all available at the moment of sale.

OTA updates have more near-term benefits of turning on new features and deploy services through software for many systems, not just the ADAS system, without having to change the hardware. Examples include optimizing electric engine efficiency algorithms to improve range, or adding something as simple as an updated convenience

feature such as deploying a partially open sunroof setting.

HOW OTA UPDATES WILL ENABLE DISRUPTIVE BUSINESS MODELS

Vehicles have a long design and life cycle, yet their business model is primarily dependent on the largest monetization at the point of sale, while the post-sale monetization has historically been limited to parts and hardware services. The provision of improved or additional functionalities via OTA updates is a way in which OEMs can shift from a transactional relationship to ongoing monetization of the installed base throughout their vehicle's life span. OTA software and feature updates are a central element of software-defined vehicles that could become a continuous revenue source to OEMs as additional functionalities throughout all domains are enabled throughout the vehicle's lifecycle.

Functional OTA updates will be key with regards to enabling automotive subscription business models. First of all, new features deployed over the lifetime of the subscription will encourage higher renewal rates. Secondly, the subscription business model will benefit from incremental increases in the monthly subscription fee, with functional OTA updates without requiring an extra trip for car service. This will require both OEMs and their supporting supply network to become much more agile in their approach. Instead of tying software development and delivery to the launch of new model generation, more agile software development approaches will support incremental revenue extraction from vehicles already in the field, whether privately owned or leased as part of a flexible subscription. Moreover, it helps build an ongoing customer relationship and customer loyalty that can generate additional revenue streams, such as frequent maintenance at the dealership, and revenue-generating touchpoints, such as in-vehicle commerce and other use cases as shown in Fig 1. Another key to ensuring renewal and adoption will be effective software management at the fleet platform level, maximizing uptime and ensuring an uninterrupted mobility experience for the consumer. This will involve the use of vehicle telematics data for remote diagnostics and predictive maintenance, maximizing the value of the all-inclusive subscription payment for the consumer.

By establishing an ongoing, revenue-generating relationship with the vehicle throughout the lifecycle of the vehicle, rather than just with the original owner of that vehicle, OEMs can better tie their revenue potential to the installed base of vehicles on the road, rather than uniquely to new vehicle sales, which can fluctuate significantly throughout the macroeconomic cycle, and which will be subdued for years due to the impact of COVID-19. By aggregating, normalizing, and enriching these datasets, OEMs can enable new connected car services and improve the quality of existing connected car services, giving OEMs access to a revenue stream proportional to the millions of connected cars that they have already shipped.

Therefore, vehicles should always have headroom for additional OTA updates, and these will typically happen over a Wi-Fi network to ensure effective coverage and while avoiding a significant increase in cellular data consumption. Given the enormity of data generated and the frequency of updates required (Tesla releases OTA updates every 16 days on average), automated driving systems will require constant essential maintenance OTA updates. This can only be enabled by the highest security standards, high performance Wi-Fi networks that can seamlessly download and upload data rapidly, and an effective vehicle network including high-bandwidth data buses such as Ethernet but still including the lower power data connections long used in automotive such as CAN and LIN.

THE OTA MARKET OPPORTUNITY

The monetization opportunity from the deployment of new features OTA will continue to rise at a constant growth rate within the next years as a growing installed base of hardware-rich passenger vehicles is upgraded by consumers. After that the frequency of updates will start dropping and a large part of the monetization opportunity will be led by on-demand purchases of features for a period of time or mileage. As Charts 2 and 3 demonstrate, according to ABI Research, there will be nearly 70 million OTA enabled registered vehicles by 2030, while functional OTA update revenue is expected to reach well over US$ 20 billion at this time. Revenues from AV software subscriptions are forecasted to significantly surpass hardware revenues from 2025, highlighting how vital software will become to vehicles and the important role OTA updates will play as contributors to OEMs' revenues. This will place wireless connectivity decisions at the forefront of decision making for automotive OEMs in the near future.

Chart 2: Global OTA Enabled Registered Vehicles by SAE Level, 2020 to 2030

Source: ABI Research

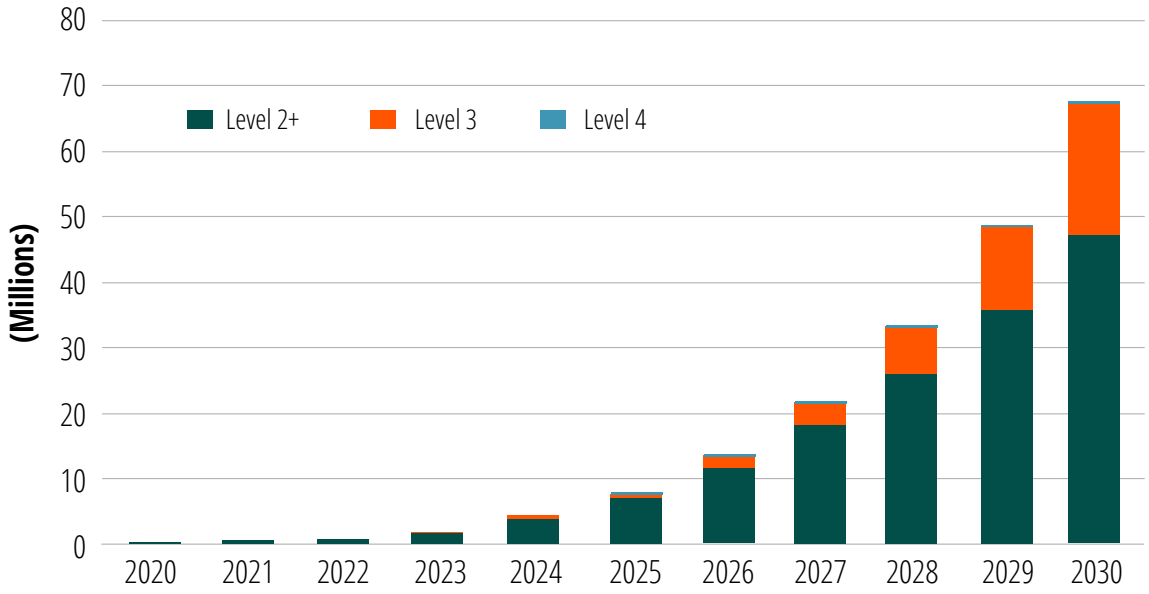
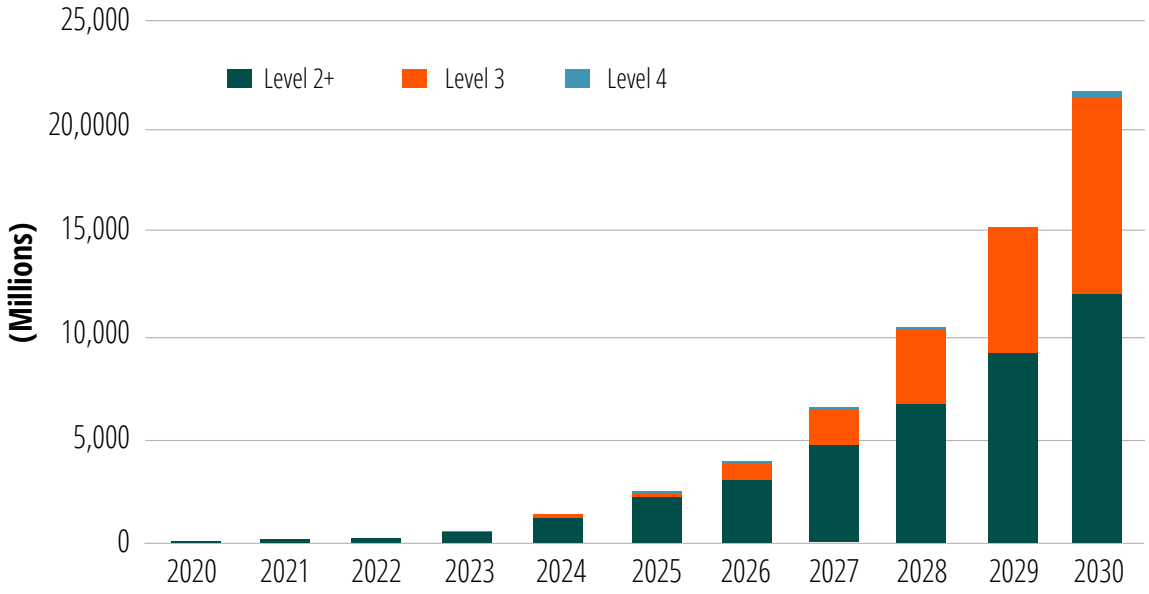


Chart 3: Functional OTA Update Revenue by SAE Level, 2020 to 2030

Source: ABI Research



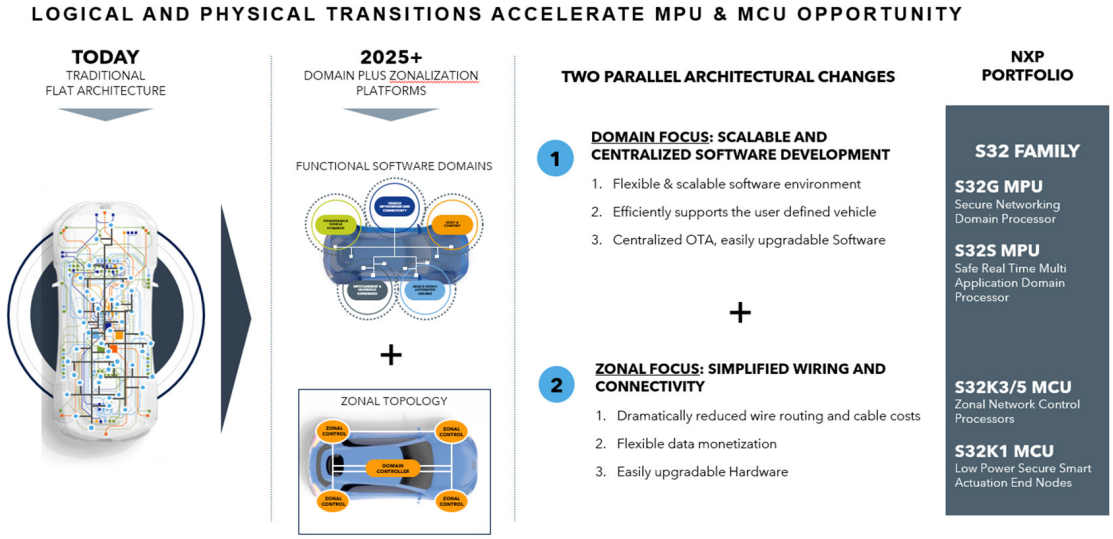
THE TRANSITION TO SOFTWARE-DEFINED VEHICLES: CHALLENGES AND REQUIREMENTS

However, there are a number of requirements and challenges around this transition towards more software-defined vehicles. Firstly, the traditional decentralized approach to vehicle architecture where new ECUs are added to support each new feature with its own processing and connectivity is not able to scale thanks to its complexity, resulting in slower development times, difficulty in assembly, security issues, and difficulty in updating features after the POS, resulting in shorter vehicle lifespans and an inability to support the evolving needs of electric and autonomous vehicles.

As a result, as Figure 3 demonstrates, the automotive vehicle architecture is undergoing a transformation away from flat hardware-based designs towards domain and zonal compute architectures.

Figure 3: Vehicle Architecture Transformation

Source: NXP



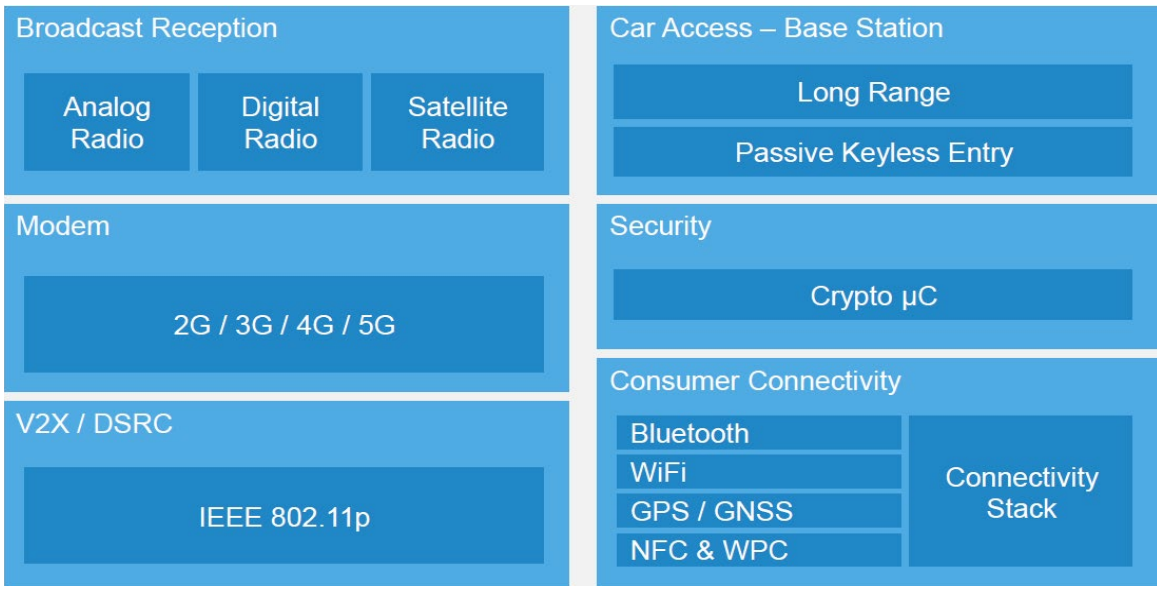
In domain-based architectures, the vehicle's logical or software systems are split into five major different functional areas, including connectivity, infotainment, ADAS, powertrain, body and comfort, which groups together the strategic hierarchy supported on a domain controller to create a flexible software platform. This will transform vehicles to be able to rapidly add software features, and paired with OTA for deployment, will get them into new vehicles faster.

The physical construct of the vehicle will be simplified by a move to zonal topology where processing is concentrated within zones of a vehicle, such as left-front, right-front, left-rear and right-rear, with a central vehicle computer. Through zones, a simplified network across the vehicle is established, and each zone manages the physical network deployment of data, power, and other needed information to the end nodes. The wiring harness can be greatly simplified as a result, providing weight, cost and reliability benefits to OEMs. Paired with the software platform from domain control implementations, a domain + zonal architecture modernizes the vehicle and creates a scalable platform for rapid hardware and software updates in the future.

The key for this will be the connectivity domain controller. As Figure 4 shows, the connectivity domain controller is responsible for radio reception, cellular connectivity, DSRC V2X communication, and secure car access, alongside consumer connectivity including Bluetooth, Wi-Fi, GNSS, and NFC.

Figure 4: Automotive Connectivity Domain Controller

Source: NXP



THE GROWING IMPORTANCE OF CYBERSECURITY

With the rise of connected vehicles, security against cyberattacks becomes even more critical. As the numerous connected applications detailed throughout this whitepaper demonstrate, the security of the vehicle must become a primary focus and key component of vehicle design and architecture decisions thanks to the vast increase in potential attack vectors. These range from applications such as vehicle access control applications, smartphone and device interaction, Wi-Fi and cellular cloud connectivity and services, server breaches, as well as a variety of in-vehicle vulnerabilities ranging from the infotainment system to diagnostic dongles, sensors, and other electronics systems. Vehicle to vehicle and vehicle to infrastructure applications also open up additional attack vectors, whereby vehicles can be infiltrated by potential smart city vulnerabilities or be leveraged in order to hack into the smart city infrastructure, causing even wider impacts to public safety. Furthermore, as vehicles become more autonomous, ensuring that vehicles cannot be infiltrated becomes increasingly safety-critical. As a result, connected automotive solutions must be developed with security at the forefront.

From an architecture perspective, by leveraging a service-oriented gateway, this enables vehicles to decide exactly where to unpack OTA updates and how and when it is delivered into different parts of the vehicle. In previous architectures, OTA updates often were controlled through the infotainment realm, making it possible to send something from this low-criticality domain into the powertrain ECU, causing an enormous potential security and safety breach. In contrast, the new domain architecture means the OTA updates securely are downloaded over cellular or Wi-Fi to the connectivity domain controller where they are authorized, and sent to the vehicle networking service-oriented gateway. Where they are further verified and distributed across the vehicle securely, making it much more difficult for hackers to overcome. This separation of connectivity from each function also ensures that connectivity hardware does not need to meet the same temperature and robustness requirements as other areas, resulting in less expensive designs, while each domain will have its own unique functional safety requirements. NXP's S32G vehicle network processors include hardware security engines for secure boot and accelerated security services along with advanced functional safety hardware and software for ASIL-D systems.

In addition to the service-oriented gateways, NXP's wider portfolio of automotive solutions have been designed with security at the forefront. For example, NXP's i.MX 8 processors leveraged within infotainment, telematics and other applications also include encrypted secure boot, cryptographic, secure key storage, and other security features designed to meet stringent automotive security standards. Dedicated hardware security modules that run independently can provide additional security without impacting the core functionality of the processors, while providing OEMs with the ability to provide secure OTA updates once the vehicle is deployed, avoiding costly recalls. Other solutions including secure CAN transceivers, Ethernet switches, and secure elements for V2X and secure access applications can help to ensure authenticity and privacy across the entire vehicle architecture.

CLOUD PARTNERSHIPS

Enabling this software defined approach will also require the close collaboration of automotive edge computing with cloud processing. Cloud partnerships will enable OEMs to unlock the full potential of the extensive vehicle data, allowing for valuable new service and business model creation. Automotive processing and connectivity solution providers such as NXP have recently partnered with Amazon Web Services (AWS) and other cloud service providers to streamline this process. In November 2020, NXP announced that its S32G processor for service-oriented gateways would leverage AWS IoT Greengrass and AWS IoT Core for vehicle and cloud data processing and storage, Amazon SageMaker and Amazon SageMaker Neo to build, train and deploy optimized ML models, and AWS Connected Mobility Solution for fleet management.

THE IMPORTANCE OF WI-FI 6

To achieve the data flow required for OTA, vehicles must also be equipped with futureproof high-speed wireless networking connectivity technologies such as Wi-Fi 6 to help offload this data. While 5G will bring improved speeds, uploading this data via a cellular connection will likely be too expensive due to cellular subscription models. In addition, coverage may be limited in the shorter term, and Wi-Fi offload is still projected to increase with the 5G rollout. Cisco projects that by 2022, nearly 60% of cellular traffic will be offloaded to Wi-Fi, while 71% of 5G traffic is projected to be offloaded to Wi-Fi. As a result, Wi-Fi 6 enabled vehicles that can seamlessly upload data or download OTA updates at home, at the dealership, or in other public locations will be a key factor in unlocking these new features and service models.

Wi-Fi 6 represents the sixth generation of Wi-Fi technology, and brings several new features and enhancements to help deliver significant performance benefits across a number of metrics including robustness, reliability, range, throughput, capacity, efficiency, and latency, among others. Wi-Fi 6 represents somewhat of a break from traditional Wi-Fi standards in that it seeks to provide more efficient real-world performance rather than simply improving peak throughput capabilities, resulting in reduced latency, range increases, 4x increase in average throughput, increased data rates, and reduced power consumption. Alongside this, Wi-Fi 6 and its new features have recently been extended into the 6 GHz band, now known as Wi-Fi 6E. The technology will bring about much higher throughput, much more capacity, greater reliability, lower latency, and better quality of service (QoS) than ever before, solving many of the key challenges that Wi-Fi is facing today. This 6 GHz band will also form the foundation of Wi-Fi 7, which will aim to provide further increases in throughput, aiming to support 30 Gbps, as well as improvements in latency and jitter of the technology. The new standard will seek to better target ultra-high-performance applications such as 8K streaming, low latency AR/VR applications, remote office, cloud computing, automotive infotainment and offload, and other use cases.

As vehicles become more autonomous in the longer term, technologies such as Wi-Fi 6, 6E, and Wi-Fi 7 will help to deliver a more efficient method of transferring the high-value, high-volume autonomous vehicle data. With up to several Terabytes of data per day being generated, data will need to be transferred efficiently over both high performance cellular and Wi-Fi networks. However, due to cellular data costs, the vast majority of data uploads are likely to be done over Wi-Fi. Autonomous vehicles parked at a charging spot, service centre, or at home will be able to connect to a Wi-Fi 6 or 6E hotspot and transfer this data. As Figure 5 shows, companies such as Cisco and Oxbotica have recently partnered to enable autonomous vehicles to connect to OpenRoaming-enabled Wi-Fi hotspots that will allow these vehicles to roam between Wi-Fi and cellular networks for optimal data upload without the need to manually enter credentials.

Figure 5: Autonomous Vehicle Wi-Fi Offload Partnership

Source: Cisco, Oxbotica

At the same time, thanks to Wi-Fi 6's long-distance protocols, range can be increased by up to 20 meters while providing an equivalent data rate. This will enable vehicles to more easily connect to home and public access points, while a typical 2 GB software update will be completed in 10 minutes via Wi-Fi 6 versus 18 minutes via Wi-

Fi 5, resulting in vehicle downtime being shortened by more than 40%. This will also ensure that users are able to regularly download updates without resorting to traveling to a dealership and back, ensuring that vehicles remain compliant with any safety updates, that unremedied vehicles on the road are reduced, and that product recalls and issues can be resolved in a timely fashion.

Additionally, Wi-Fi 6 can also bring benefits to automotive manufacturers and OEMs on the factory floor, allowing vehicle software with large file sizes to be transferred wirelessly and be installed on more vehicles simultaneously, reducing installation times and enabling a swifter and more flexible vehicle production process. There is growing demand for OEMs to be able to install production OTA updates without plugging in ethernet on the factory floor, resulting in the need for robust, higher speed Wi-Fi.

In addition, higher Wi-Fi throughput and downlink and uplink Multiple Input, Multiple Output (MIMO) support are also desired to help enable the vehicles to act as client devices and connect to external APs for a variety of automotive services, including software updates, uploading of vehicle diagnostic data, data downloads, and automatic check-ins when arriving at dealerships and other areas. TWT can provide additional benefits, reducing the drain on vehicle batteries while the vehicle is off, and allowing it to wake up periodically to receive vital updates and software upgrades even when switched off for extended periods of time. Additional features such as 8 stream sounding will allow vehicles to take full advantage of higher end 8x8 MU-MIMO access points for higher throughput.

Figures 6 and 7 below shows key requirements for Wi-Fi bandwidth at home and within production environments or dealerships across different use cases. Future use cases such as OTA updates and data offloading will take full advantage of Wi-Fi 6's bandwidth to enable more swift updates than previous Wi-Fi standards.

Figure 6: Parked at Home Wi-Fi Connectivity Bandwidth Requirements

Application	2.4 GHz / 5 GHz	Assumption	BW (Mbps)
OTA updates OR data offloading	2.4 / 5	Available BW	1,077
car charger	2.4	basic communication	10
child presence detect	5	30Hz ping packet	2
overhead		*20%*	*272*
Total Available Bandwidth (2.4G + 5G)		**2.4G + 5G, 256 QAM**	**1,361**

Application	2.4 GHz / 5 GHz	Assumption	BW (Mbps)
OTA updates OR data offloading	2.4	Available BW	356
car charger	2.4	basic communication	10
child presence detect	*5*	*30 Hz ping packet*	*2*
overhead		*20%*	*92*
Total Available Bandwidth (2.4G)		**2.4G, 256 QAM**	**458**

Figure 7: OEM or Dealership Wi-Fi Connectivity Bandwidth Requirements

Application	2.4 GHz / 5 GHz	Assumption	BW (Mbps)
OTA updates	5	Available BW	960
overhead		*20%*	240
Available Bandwidth		**5G, 1024 QAM**	**1,200**

Increasingly, automotive Wi-Fi chipsets such as NXP's 88Q9098 solution support concurrent dual Wi-Fi architectures that can enable two separate 2x2 data streams to run simultaneously, enabling higher data rates and concurrent use cases, while inherent Wi-Fi 6 features such as OFDMA and BSS Coloring help mitigate congestion

and offer better provision for more users at once. NXP's RF front-end ICs, such as the WLAN7002CC, can also improve the overall system performance with their high linearity and power efficiency. These solutions provide peak throughput of up to 1.6 Gbps, enabling rapid uploading vehicle sensor data or downloading of OTA updates among other use cases. NXP also offers a complete Telematics platform that incorporates SoC, Wi-Fi, Bluetooth, VX2, UWB, and Ethernet connectivity for optimal external connectivity.

NXP's automotive connectivity chipsets have been leveraged in a variety of connected automotive deployments while there are several automotive module makers who are leveraging NXP's RF Front End ICs in modules that are sold to automotive Tier 1 suppliers.

To summarize, the transition towards software-defined vehicles and service-oriented gateways combined with high performance Wi-Fi standards, such as Wi-Fi 6, will help to enable optimized vehicle-to-cloud connectivity which can effectively extract valuable vehicle sensor information to enable new OTA services and business models. NXP's portfolio of service-oriented gateway network processors alongside its comprehensive Wi-Fi 6 portfolio make it well placed to address these growing requirements.

ABI Research therefore expects Wi-Fi 6 to become a fundamental aspect of in-car connectivity in the years to come, while in the long run, vendors will increasingly incorporate 6 GHz Wi-Fi 6E and Wi-Fi 7 as it becomes more widely available, thanks to higher throughput, additional capacity, and the ability to leverage more 160 MHz channels. As Chart 4 demonstrates, by 2026, ABI Research anticipates around 80% of the automotive market to have transitioned towards Wi-Fi 6 and above technologies. While Wi-Fi 5 will exist for some time, thanks to more lengthy vehicle design cycles, automotive OEMs should not hesitate in transitioning towards these new standards. This will ensure that vehicles are futureproofed and able to support many of the growing demands from connected vehicles.

Chart 4: Automotive Wi-Fi Chipset Shipment Share by Protocol, 2020 to 2026

Source: ABI Research

As OTA updates and increased telematics data offload increase over time, the vehicle of the future is likely to integrate additional Wi-Fi and Bluetooth combo nodes, differentiating between those dedicated to in-vehicle infotainment experiences and those centred on external applications such as home OTA updates. The need for higher performance and reliability will likely lead to dedicated Wi-Fi chipsets that service these functions, while demands will only grow over time as bandwidth and reliability requirements for both infotainment and telematics increase over time. This will also place additional incentive on migrating to new Wi-Fi 6 and above standards.

IN-VEHICLE EXPERIENCE

GROWING INFOTAINMENT DEMANDS

Alongside telematics and other vehicle to cloud use cases, wireless connectivity is of growing importance to the in-vehicle experience. Drivers now expect their vehicles to deliver similar user interfaces (UI) to that of their smartphones and tablets, smart televisions, smart speakers, and other Internet of Things (IoT) devices. As a consequence, many trends in the infotainment realm derive from efforts to implement consumer device technologies in vehicles. What was once just Bluetooth hands-free calling has already evolved to support smartphone-based platforms such as Baidu CarLife, Android Auto, and Apple CarPlay, in addition to audio and Rear Seat Entertainment (RSE) streaming, and vehicle as hotspot applications. In addition to key emerging trends such as voice commands and voice assistants, vehicles are increasingly becoming comprehensive entertainment and connectivity hubs, evolving to support digital cockpits with multiple displays, rear seat infotainment, gaming and wireless video streaming, enhanced audio experiences, wireless interior and exterior wireless cameras, and act as Wi-Fi hotspots for growing numbers of personal devices. Enhancements via Wi-Fi 6 and Bluetooth 5.2 will be critical in enabling many of these use cases. Furthermore, as vehicles transition to level two and above (L2+) autonomy, growing demands will be placed on infotainment as a core differentiator, while engine, driving performance, and other traditional elements will become less relevant when most vehicles on the road are electric. In this context, the digital experience becomes an increasingly critical element. This has been clearly demonstrated by the likes of Tesla, who have focused heavily on vehicle entertainment to help reduce the pain of waiting for the vehicle to charge, and Mercedes' decision to launch its Hyperscreen on an EV. CES 2021 featured numerous announcements of large displays with seamless HMI, AI-based infotainment systems that provide increased personalization, ADAS sensors like DMS and OMS being used to create infotainment experiences, and a strong focus on media streaming and gaming features, demonstrating that the digital experience has become the carmakers' priority.

IN-CAR VIDEO STREAMING AND GAMING

In-car video streaming is a functionality on the rise that will become increasingly popular among autonomous vehicles as an entertainment option during charging or when parked. Tesla Theater, for example, enables in-vehicle video streaming from YouTube, Netflix, Hulu, and Twitch while the vehicle is parked. Gaming is another functionality that has gained interest in recent months. Tesla Arcade now also includes games such as Beach Buggy Racing 2, Cuphead, and Stardew Valley. In addition, the company recently announced that its new Model S will include a 10-teraflop capable gaming computer to deliver a console-like experience equivalent to current generation consoles such as the PS5, alongside support for wireless controllers. Meanwhile, Harman also recently unveiled its Gaming Intense Max solution which seeks to provide immersive gaming experiences including multiplayer, high resolution graphics, and live video game streaming, and wireless controllers. As these in-vehicle systems support higher performance, much like in the game console realm, there will be a desire to support low latency online multiplayer via Wi-Fi 6, as supported in the PS5. However, in the future, game streaming platforms like Google Stadia could also be utilized when parked, reducing processing requirements for high quality gaming experiences and instead relying on a high-quality external cellular or Wi-Fi 6 connection.

OTHER INFOTAINMENT USE CASES

Wi-Fi 6's combination of high-throughput with more efficient networking will bring significant benefits to the infotainment space, enabling better performance for use cases such as UHD video streaming on multiple displays, wireless video mirroring, and support for multiple cameras around the vehicle to assist with parking, collision avoidance, and other safety applications.

At the same time, there is greater demand for vehicles to be leveraged as Wi-Fi hotspots both on the road and when arriving at a destination, with a desire to support high throughput for an increasing number of users via single vehicle hotspot. Wi-Fi 6 features such as BSS Coloring could help reduce external interference and provide a much more stable vehicle-to-device connection.

Additional features of Wi-Fi 6 including TWT can enable smartphones to use considerably less power when streaming or Wi-Fi calling in the vehicle compared to previous Wi-Fi generations, extending battery life and providing a better user experience. As the personal devices of vehicle owners increasingly support Wi-Fi 6, greater expecta-

tions will be placed on the vehicle to also support the technology. Consumers continue to demand better performing Wi-Fi, and as Wi-Fi 6 penetration in Wi-Fi access points and smartphones increases, the expectation will be that their vehicle can also support the technology going forward. By 2026, ABI Research forecasts that 72% of smartphones will come equipped with Wi-Fi 6 and above technology. OEMs will no longer be able to afford a negative in-car experience as advanced infotainment capabilities becomes increasingly vital to purchasing decisions.

Figure 8 shows the growing bandwidth requirements for Wi-Fi related in-car infotainment experiences in the short and longer term. Growing requirements such as 4K displays, higher resolution cameras, and more demanding hotspot devices will require taking full advantage of Wi-Fi 6's increased capacity over time. As a result, there is a clear need to futureproof the in-vehicle connectivity in order to provide a consistent user experience as these demands increase and required bandwidth stretches to well over 1 Gbps.

Figure 8: Evolving Wi-Fi Infotainment Bandwidth Requirements

Qty	Application	2.4 GHz / 5 GHz	Assumption	BW (Mbps)	Total
1	Apple CarPlay	5	per spec (Mbps): 20 TCP + 6 UDP	30	30
4	RSE streams	5	FHD (1,920x1,080, 30fps, H.264)	25	100
2	in-cabin cameras	5	FHD (1,920x1,080, 30fps, H.264)	25	50
2	exterior (trailer, assist) cameras	2.4 / 5	FHD (1,920x1,080, 30fps, H.264)	25	50
4	hot-spot devices	2.4 / 5	FHD (1,920x1,080, 30fps, H.264)	25	100
	overhead		*20%*		*66*
	Total Bandwidth				**396**
	Available Bandwidth				**1,600**

>2026					
Qty	**Application**	**2.4 GHz / 5 GHz**	**Assumption**	**BW (Mbps)**	**Total**
2	Apple CarPlay	5	forecast (Mbps): 40 + 12	60	120
4	RSE streams	5	4K (4096×2160, 30fps, H.265)	50	200
4	in-cabin cameras	5	4K (4096×2160, 30fps, H.265)	50	200
4	exterior (trailer, assist) cameras	2.4 / 5	4K (4096×2160, 30fps, H.265)	50	200
6	hot-spot devices	2.4 / 5	4K (4096×2160, 30fps, H.265)	50	300
	overhead		*20%*		*204*
	Total Bandwidth				**1,224**
	Available Bandwidth				**1,600**

In addition, as the number of simultaneous Wi-Fi related use cases both in and outside the vehicle grow, this will significantly increase the risk of congestion and diminished performance. As a result, key features in Wi-Fi 6 such as OFDMA that divides the radio channel into smaller sub-channels to transmit to multiple users at the same time in order to reduce frequency fading and interference issues will be vital in ensuring that the increasingly dense automotive environment can still offer reliable and robust performance. This will also help mitigate the effects of contention. BSS Coloring can also help reduce interference from multiple overlapping networks within the vehicle, resulting in more simultaneous transmissions.

WIRELESS ECU INTERCONNECTS

As discussed, wireless connectivity within the vehicle is set to expand to a growing number of applications, each with their own unique requirements around throughput, range, congestion, robustness, and reliability. As a result, there is a growing need for multiple Wi-Fi and Bluetooth chips per vehicle. In the longer term, this could enable Wi-Fi to be leveraged as a wireless link between different automotive ECUs such as telematics units, digital video recorders, and rear seat media hubs. This can have several benefits, including a reduction in total system cost thanks to Wi-Fi chips being more affordable than high speed wired solutions, alongside potential weight savings through the avoidance of more bulky cables and connectors, as well as better congestion management through the avoidance of additional cabling. This will allow passengers in the rear to connect with the rear seat Wi-Fi and Bluetooth media hub, optimizing performance and minimizing congestion. Technologies, such as Wi-Fi 6E thanks to its clean 6 GHz band, could also be leveraged to provide a clean link between distributed areas of infotain-

ment. This will provide high performance in-vehicle networking between various end points such as the digital cockpit, rear seat media hub, and telematics units.

In-cabin wireless connectivity has different characteristics compared to external connectivity, e.g., antennas, range, use cases, etc. By leveraging multiple chips, this can provide optimal connectivity for each use case. For example, telematics Wi-Fi chips can be placed in the most optimal location that enable higher performance for external connectivity.

BLUETOOTH ENHANCEMENTS

Bluetooth's role within the vehicle is also expected to expand beyond what was once hands-free calling and audio streaming to support multiple new concurrent automotive user experiences. This will likely require the use of multiple Bluetooth chipsets in order to meet performance demands.

As in-car gaming experiences become more common, there is a need for robust Bluetooth connectivity that can support multiple wireless gaming controllers. When parked, passengers will be able to connect their smartphones or a wireless Bluetooth controller to the infotainment system to play games. In addition, passengers could connect their Bluetooth headset to the infotainment system to have privacy for phone calls, gaming, or watching videos. The arrival of LE Audio will also enable improved audio quality and experiences within the vehicle. The Low Complexity Communications Codec (LC3) improves audio quality at lower data rates, optimizing the balance between audio quality and power consumption. LE Audio will also introduce Broadcast Audio, a new feature which allows an audio source device such as an automotive infotainment or rear seat entertainment system to broadcast an audio stream to a potentially unlimited number of devices within range. Upcoming automotive grade Wi-Fi and Bluetooth 5.2 chipsets from NXP will support both Wi-Fi 6 and Bluetooth 5.2 LE Audio functionality. OEMs are also introducing new ideas such as Bluetooth cabin control. Vehicle passengers will be able to control their own lighting, air conditioning, heating, and seat position via their smartphone and Bluetooth Low Energy.

Further emerging potential use cases for Bluetooth within the vehicle include the use of driver monitoring wearables. With the growing feature sets of wearables such as smartwatches that include the ability to detect heart rate, bloody oxygen levels, stress levels, sleep quality, temperature, and other physical and health metrics, these devices can be leveraged by the vehicle head unit to adapt the vehicle environment to optimize driver comfort, safety, awareness, and detect fatigue. For example, Mercedes-Benz and Garmin recently partnered to enable certain Garmin smartwatches and fitness trackers to network with the vehicle via Bluetooth. As part of the Mercedes-Benz Energizing software service package, the Energizing coach offers tailored programme recommendations that combine vehicle data such as traffic conditions, weather, and journey time with the driver's physical and mental state information. The Energizing coach then adapts the vehicle's music, lighting, temperature, massage function, and other functionalities to help ensure maximum comfort. As more and more wearables also incorporate technologies such as Bluetooth, NFC, and UWB, these same wearables can also be used for the secure keyless entry for vehicle access and vehicle start. Other use cases in the future may include tire-pressure monitoring systems or other automotive sensors that can enable direct connectivity to a smartphone or Bluetooth enabled head unit.

Combined, these growing use cases will ensure that more devices are connected to the in-car Bluetooth than ever before, and that many of these will be used at the same time. The bandwidth required will likely exceed the capacity of a single Bluetooth chipset, reaffirming the need for multiple Bluetooth and Wi-Fi chipsets within the vehicle. However, growing congestion in the 2.4 GHz band between multiple Wi-Fi and multiple Bluetooth chipsets will require much smarter coexistence and optimized channel allocation. Many automotive chipset providers are working on smarter coexistence solutions that maximize the throughput of both technologies when used concurrently, while others offer discrete front-end configurations to accommodate both technologies more effectively. The arrival of Bluetooth Low Energy Power Control in Bluetooth 5.2 will also help to optimize power consumption of connected devices, ensure a good link quality, and minimize interference with nearby Bluetooth devices. This will be critical in highly congested deployment scenarios, such as in-vehicle environments, with

multiple concurrent devices and use cases. Bluetooth will also play a fundamental role in enabling secure vehicle access, predominantly as the initial wake up technology which will then handover to UWB for secure ranging. Recent enhancements to Bluetooth's range will also be of benefit here.

OTHER IN-VEHICLE EXPERIENCE TECHNOLOGIES

Complementing Wi-Fi and Bluetooth ICs, automotive solution providers such as NXP offer additional technologies to support a better in-car experience. Live radio remains an important source of live entertainment and audio experiences for much of the population. In Europe, it is estimated on average that 85% of the EU population listens to broadcast radio each week for nearly 2.5 hours a day. Broadcast radio is incumbent for car infotainment systems for several reasons including better coverage, quality-of-service, and robustness in cases of emergency. There are plenty of examples including the most recent flooding in Germany where the cellular network was quickly disrupted but radio continued to function as normal. Broadcast radio transmission is much more robust as it is easier to protect against disasters due to fewer transmitters (more reach), redundancies of transmitters, and special secure locations for transmitters. As a consequence, many countries mandate radio reception (e.g. EU: DAB, UAE: AM, China: CDR under discussion) as a minimum requirement for emergency situations.

Although traditional broadcast radio does not offer the important back channel from the customer, it is still integrated due to its many advantages:

- Much better coverage, especially in rural areas and along motorways
- Robust technology
- Independence from cellular network data plans
- Established and proven emergency infrastructure
- Broadcasting "one-to-many": Offloading cellular network
  - 100-200kbit/s per listener & per cell 10-20Mbit for 100 cell participants

NXP's unique wideband tuners can offer a significant cost, space, and power reduction by removing the need for multiple narrow-band tuners that perform single tasks such as receiving analog radio, analog station lists, digital radio, and digital station lists. This enables a single tuner to capture full bands instead and enable multiple station derivatives from a single tuner.

NXP's portfolio also includes in-car NFC for potential use cases such as driver authentication for engine start, seamless pairing of personal devices to the automotive Bluetooth or Wi-Fi, as well as a simplified way of recognizing the driver and personalizing the air conditioning, seat, and mirror settings to their preferred settings. In addition, NXP's NFC and MIFARE ICs for smart card solutions can also be leveraged for vehicle access as a back up to UWB, which is set for strong adoption in the coming years.

Alongside this, NXP offers a comprehensive portfolio of Qi charging solutions. As vehicles increasingly support wireless charging for personal devices, one emerging trend is multiple chargers per vehicle, with the potential to eventually offer one charger per person over time. NXP is the first MCU manufacturer that can support two chargers via single MCU, providing a big benefit in terms of cost reduction, while being able to synchronize chargers to avoid any interference.

SHARED ACCESS AND SMART MOBILITY

SECURE VEHICLE ACCESS

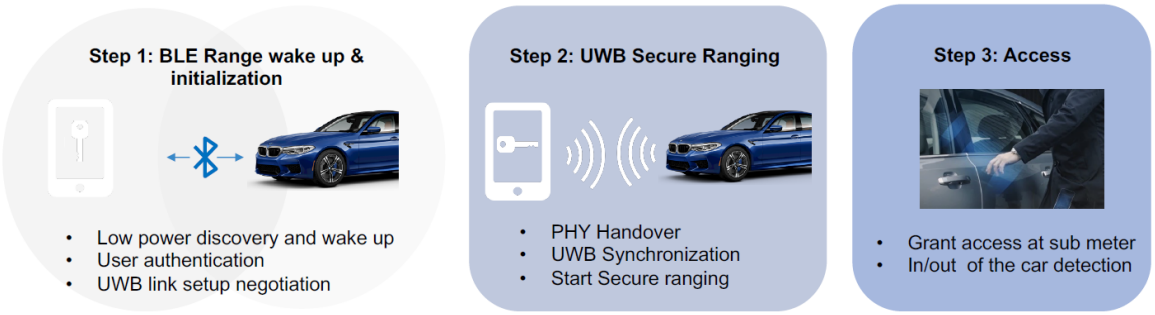
Ultra-Wideband (UWB) has re-emerged as a secure, fine ranging technology capable of enabling a wide range of innovative location-based user experiences and services that previous wireless technologies have been unable to effectively support. This includes a combination of device-to-device and device-to-infrastructure applications, including hands-free secure vehicle and building access, indoor localization, asset tracking, hands-free payments, seamless smart home interaction and automation, augmented reality, gaming, and a whole range of emerging smart building, smart city, industrial, and other IoT applications.

While other technologies such as Bluetooth and Low Frequency wireless communication often calculate distance and location information from signal strength via RSSI (received signal strength indication) techniques, these systems can be subjected to relay station attacks from unauthorized remote users, which involves the interception and spoofing of the wireless signals, causing false readings. As a result, there have been high-profile security breaches using wireless car key fobs. For example, in 2019, research from the German General Automotive Club (ADAC) found that 230 out of 237 cars were susceptible to attacks where thieves could unlock and start the car without having the key. However, UWB provides much greater resistance to these attacks as it is able to determine the Time of Flight (ToF) more accurately between two devices. This means it can detect when the ToF is too long for the device to truly be in close proximity, prohibiting relay attacks and determining the exact distance between devices at all times. During this test, the only cars to pass the test were leveraging UWB technology.

The desire to solve the automotive industry's challenge of providing a secure, interoperable, hands-free digital key experience has led to the resurgence of UWB technology and has encouraged more automotive and device OEMs to investigate and offer UWB enabled devices. Thanks to the availability of secure fine ranging through the IEEE 802.15.4z standard, secure car access will act as a catalyst for the first adoption wave for UWB within the automotive and mobile device industry. Of key importance to the success of UWB within the automotive space is its backing from the Car Connectivity Consortium (CCC). This organization focuses on enabling smartphone-to-car connectivity solutions across different technologies, including UWB, with an aim to provide consistent user experiences and interoperability. Its membership covers a large amount of leading car OEMs, automotive Tier 1 suppliers, phone manufacturers, chipset vendors, security product suppliers, and app developers. Its board of directors includes individuals from Apple, BMW, GM, Honda, NXP, Samsung, VW, and more. Through its Digital Key 3.0 specification, released in July 2021, the CCC is seeking to create an open standard that allows smart devices such as mobile phones to function as a key that will seamlessly lock, unlock, and start vehicles from the pocket. It will also allow these devices to store, authenticate, and share digital keys with friends, co-workers, family, or valets, providing a secure, handsfree, unified experience across all vehicles. The Digital Key 3.0 specification builds on the 2.0 specification defining the underlying Digital Key Management architecture as well as the NFC communication protocol. To this CCC digital key 3.0 adds support for Bluetooth LE and UWB to enable a handsfree experience. As Figure 9 demonstrates, this enables initial wake up and authentication over Bluetooth and secure ranging using UWB, with NFC being leveraged as a backup technology for battery drained mobile devices, ensuring users have uninterrupted access at all times. NXP's MIFARE & JCOP IC solutions for smart card are a rare perfect fit for an alternative backup card key leveraging on the same NFC interface.

Figure 9: Secure Vehicle Access via Ultra-Wideband

Source: NXP, FiRa Consortium



There is already growing momentum for UWB within car access. In January 2021, BMW announced that the BMW Digital Key Plus with UWB technology will be coming to the BMW iX electric vehicle range, promoting UWB's strong precision and its ability to prevent relay attacks. The solution is based on the Car Connectivity Consortium's Digital Key 3.0 specification, and is supported by iOS 14 UWB enabled iPhones.

In July 2021, the CCC announced that its CCC Digital Key Release 3.0 specification was finalized and now available to CCC members. This is a vital step in helping to accelerate awareness and adoption in the coming months and years.

Mobile devices such as smartphones store digital keys within a Secure Element (SE) to protect against hardware and software-based attacks. Vehicle owners can therefore share digital key credentials with friends and family, granting them temporary access to their vehicle as required. New automotive sharing business models can also be created. For example, owners could temporarily rent their vehicle while away on vacation, avoiding the need to pay for a parking garage in a similar way to room hosting platforms today. Here, they could leverage digital keys to provide access without relying on the transfer of physical car keys. Fleet operators can more easily provide temporary access to personnel without the need to reprovision physical key cards or fobs. Access could be granted to repair personnel or when a vehicle is towed and can also be terminated or suspended without the need to retrieve a physical key or fob. UWB enabled smartphones could also help direct users to the correct vehicle or taxi when being picked up or in a parking lot, while UWB offers additional potential for gesture recognition, enabling users to open the trunk or vehicle doors by learning a personalized gesture. Thanks to UWB's precision, it can also determine when the user is inside or outside the vehicle. This means that users can open and start the vehicle all the while leaving their phones in their pockets or bags, providing a much improved and seamless user experience.

In addition, there are a number of potential future applications for UWB within vehicles, including paying for valet parking automatically, and car-as-a-key where a UWB enabled garage door lock would unlock as the vehicle approaches it. Authorizing delivery to connected car trunks/boots is another useful application. Future use cases could include precise autonomous parking. Other potential future use cases for UWB also include radar, offering the ability to remotely measure a driver's heart rate and respiration within the vehicle without requiring physical contact. As driver monitoring will also rely on camera, UWB as a ranging sensor complements the dominant camera well. This will allow for new applications including presence detection for children and pets within vehicles which will eventually be part of the EuroNCAP testing protocols.

Thanks to lengthy vehicle design cycles, it is unlikely that UWB will become ubiquitous overnight. However, ABI Research anticipates that around 25% of cars shipping in 2025 will come equipped with UWB ranging technology, with UWB expected to become the major mobile car access technology in the future. Access will be granted via the growing installed base of UWB enabled smartphones alongside dedicated smart access key fobs that embed BLE, UWB, NFC, and a secure element. Access will also be further assured with an alternate backup key card based on NFC technology. The speed of UWB's adoption will also be closely linked to the wider availability of UWB smartphones. Encouragingly, by the end of 2021, ABI Research expects over 350 million smartphone devices to have been shipped cumulatively, growing to nearly 2 billion by 2025.

To summarize, UWB is a uniquely positioned fine ranging technology with the ability to provide highly accurate, reliable, robust, and secure positioning information across a wide range of use cases and device types. These strengths have led to the initial adoption of UWB within the Car Connectivity Consortium's Digital Key 3.0 Specification, which will enable the technology to become embedded within future vehicles from leading automotive OEMs, providing more secure vehicle access and innovative user experiences. In turn, this has spurred initial adoption within flagship smartphone devices, which will soon expand into other tiers of the market, demonstrating the growing mobile commitment to the UWB ecosystem. This growing installed base of UWB-enabled smartphones will lead to the development and acceleration of new IoT use cases within automotive entry, access control, RTLS and personal tracking, and smart home, among many other verticals. NXP's portfolio of UWB, Bluetooth, NFC, and secure element solutions make it perfectly placed to provide digital key solutions within mobile devices, smart key fobs, smart key card and within the vehicle, and other emerging IoT use cases.

OTHER SMART MOBILITY APPLICATIONS

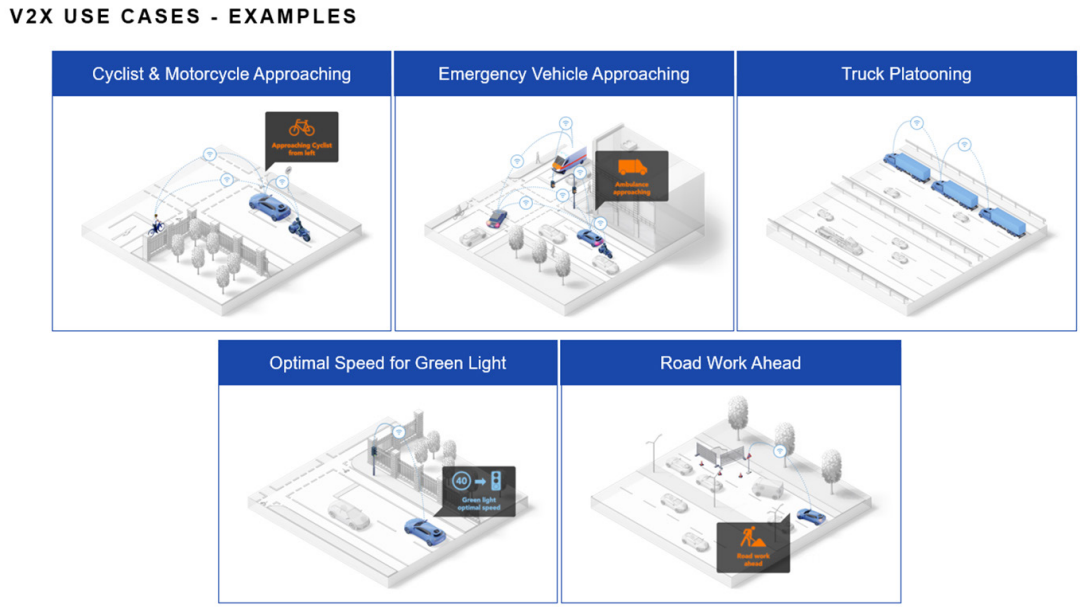
In addition to UWB, other technologies such as RAIN RFID have the potential to play a key role within the future of secure connected automotive applications. Vehicles embedded with RAIN RFID chipsets within license plates or windshield stickers can take advantage of several smart mobility applications such as vehicle identification and registration, road tolling, access control to restricted parking areas, and payment applications, among many others. RAIN RFID can provide unique benefits over alternative systems such as image recognition, active RFID, and passive RFID, including increased accuracy, range, latency, security, and lower costs. Roadside RAIN RFID infrastructure has the ability to read numerous tags simultaneously and over significant ranges. This helps to minimize the risk of not being able to identify vehicles using the same or adjacent lanes, while the quick read times ensure vehicles can be identified at speeds of up to 200kph, reducing congestion challenges and any inconvenience that may be caused by alternative identification technologies. Furthermore, as tags do not require a battery, they do not need to be replaced regularly and can be embedded in the most optimal and discreet location such as within a license plate, windscreen, or tires. RAIN RFID chips such as the UCODE DNA RAIN RFID (UHF) tag IC from NXP also highlight AES-128 cryptography for secure communications and provide a range of up to 15 meters.

V2X (VEHICLE-TO-EVERYTHING)

Another critical automotive feature enabled by wireless connectivity will be V2X (Vehicle-to-Everything) communication, which will be complementary to other sensor technologies for ADAS and autonomous driving.

It will enable direct communications between vehicles and other vehicles, vehicles and the wider smart city infrastructure, as well as vehicle to vulnerable road users, such as pedestrians, bikes, and motorcycles. Figure 10 demonstrates some example key use cases for V2X. These use cases require low latency, high reliability, and stable performance.

Figure 10: Typical V2X Use Cases



Since its announcement, V2X has been gaining market traction and certain regions have already deployed V2X technologies using Dedicated Short-Range Communication (DSRC) based on the 802.11p standard, with more and more new vehicles adopting the technology. Alongside this, in January 2019, the IEEE 802.11bd Task Group was created with the goal of improving 802.11p to support advanced applications while guaranteeing interoperability, coexistence, backward compatibility, and fairness. The 802.11bd standard aims to support vehicles with speeds up to 500 Kilometers per Hour (km/hr) compared to 802.11p with up to 200 km/hr velocity support. It will also support at least one mode that achieves twice the communication range of 802.11p. The technology is still in development, with standard finalization expected within the next 12 months.

DSRC has been implemented in vehicles in Japan since 2015, in the US since 2017, and in Europe from 2020. Notably, Volkswagen introduced DSRC as a standard feature initially in its Golf 8 and then followed by additional models like the electrical vehicles ID3 and ID4, with the expectation that it will be deployed on further vehicles in the future. These vehicles are able to send direct messages to each other to share information on local hazards such as slippery surfaces, when a car has suddenly braked, or when a vehicle has broken down, among others. Other OEMs are expected to follow VW's example, adopting 802.11p from 2021 onward. Japan is also likely to continue with the adoption of 802.11p, as well as Korea and Australia due to their C-Roads membership.

From an infrastructure perspective, there has also been a number of DRSC commitments. In Europe, there has been a coordinated rollout of V2X Road-Side Units (RSU), with 6000km of roads across 18 countries already equipped with the technology. This is part of the C-Roads platform, a joint initiative of European Member States and road operators for testing and implementing Cooperative Intelligent Transport Systems (C-ITS) and services. Features include enabling warnings to vehicles around traffic jams, hazardous areas, roadworks, emergency vehicles, optimal speed suggestion for green lights, among many others.

Alongside this, from November 2020, Austrian motorways began to be fitted with DSRC equipment to enable the exchange of safety information between the road infrastructure and vehicles. The Austrian motorway operator ASFINAG has targeted expanding this to the entire Austrian motorway network over the new few years. In Japan, a C-ITS rollout plan is in place, while in Korea a five-year C-ITS deployment has been committed to, with rollout to begin in 2021. Combined, these efforts show growing opportunities for DSRC from both the infrastructure and in-vehicle perspective. This will be fundamental if the technology is to build success. According to ABI Research, the global number of 802.11p shipments in 2020 reached 1.24 million, with nearly 7.5 million forecasted by 2024.

CONCLUSIONS AND STRATEGIC RECOMMENDATIONS

As this whitepaper has demonstrated, automotive wireless connectivity can no longer afford to be an afterthought, but is instead becoming a fundamental enabler of a vast number of future automotive use cases. There is a growing convergence of technology between the automotive world and the enterprise world, and the growth of connected cars will enable new use cases ranging from predictive maintenance to fully upgradeable software-defined vehicles.

In the coming years, there will be an enormous growth in use cases that rely upon high performance, robust, reliable, and secure wireless connectivity technologies, both inside the vehicle, outside the vehicle, and even between different components of the vehicle. Table 1 below summarizes some of the key use cases by wireless connectivity technology highlighted throughput this whitepaper. Many of these technologies will work together to support certain use cases. For example, UWB will work alongside Bluetooth and NFC in order to provide a secure vehicle entry via mobile devices. In addition, the vehicle of the future will likely need several different chipsets within the vehicle in order to address the capacity and performance requirements demanded over time.

Table 1: Key Automotive Use Cases by Wireless Connectivity Technology

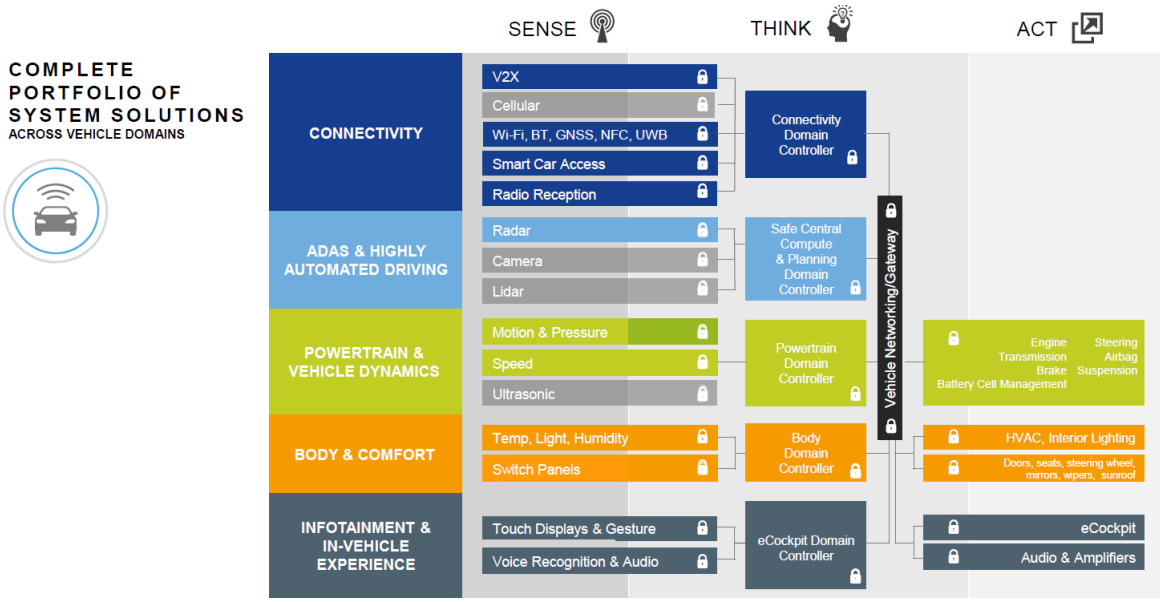
Wi-Fi	Cellular	Bluetooth	UWB	NFC	DSRC
Infotainment	Infotainment	Audio	Secure Vehicle Entry (Fine-Ranging)	Secure Vehicle Entry (Backup)	V2X
Video Streaming	Video Streaming	Gaming Controllers	Keyless Start	Keyless Start	
Gaming	Gaming	Smartphone Connectivity	In-vehicle presence detection	Bluetooth and Wi-Fi Pairing	
OTA Updates	OTA Updates	In-cabin control	Gesture detection		
Telematics	Telematics	Wearable interaction			
Wireless ECU Interconnects		Rear Seat Entertainment			
Vehicle data offload and cloud connectivity	Vehicle data offload and cloud connectivity	Calling			
Vehicle-as-hotspot	Vehicle-as-hotspot	Secure Vehicle Entry (Wake-up)			

However, improvements in wireless connectivity are not enough alone. The future of automotive connectivity has a symbiotic relationship with a shift in vehicle architecture. In order for the vision of a software-defined vehicle to be realized, it requires both innovation in the connectivity realm as well as a shift in vehicle architectures towards domain and zonal based implementations. Automotive manufacturers need to move much faster to address the software and data driven world brought on by electric, autonomous connected vehicles. However, this is not possible with existing vehicle architectures. The emergence of service-oriented gateways enabled by vehicle network processors, such as NXP's S32G, will provide secure networking access across all the different domains or zones, provide edge processing, and access to cloud services, while enabling OTA updates. These solutions bring together a technology convergence of real-time processing, automotive networks with Gigabit Ethernet, high-level operating systems (OS), virtualization capabilities, and new types of applications and services. In addition to receiving and distributing OTA updates alongside AI and machine learning models from the cloud, these devices intelligently aggregate, filter, and pre-process vehicle insights and data from sensors before transmitting it to the cloud. Service-oriented gateways that are combined with high speed, robust, reliable, and futureproof wireless connectivity will enable vehicles to safely and securely extract the relevant vehicle data that is currently not able to be utilized to provide services or intelligence. This in conjunction with cloud platforms and machine learning will enable valuable

new services, vehicle performance enhancements, new business models, and new revenue opportunities in the future. As Figure 11 shows, solution providers such as NXP who offer automotive processing solutions for service-oriented gateways via chipsets, such as the S32G, alongside processing and connectivity for connectivity domain controllers are well placed to enable this transition towards the future of automotive connectivity.

Figure 11: NXP Automotive System Solutions

Source: NXP



To summarize, automotive connectivity is no longer an add-on or afterthought but a fundamental enabler of the transition to more autonomous, electric, software-defined vehicles. OEMs should therefore futureproof their automotive connectivity with new technologies such as Wi-Fi 6, Bluetooth 5.2, and UWB, among others, in order to ensure strong user experiences today and the ability to support evolving demands within infotainment, vehicle to cloud, secure access, and V2X over time. As a result, ABI Research believes there will be an enormous growth in use cases for automotive connectivity, and there increasingly needs to be a vision that can incorporate the best of each technology while providing secure connectivity for the whole vehicle ecosystem. As demands increase, there is also a need for more tailored automotive solutions that can address these changing demands, ensuring that vehicles can maximize their connectivity performance both within and outside the vehicle. Only then will the true potential of the intelligent connected car be realized.

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