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# Development in the mobility technology ecosystem—how can 5G help?

Technology-driven ecosystems are emerging in the automotive industry. Here's what companies need to know about the new automotive technology stack, the players driving this transformation, and the issues they are grappling with.

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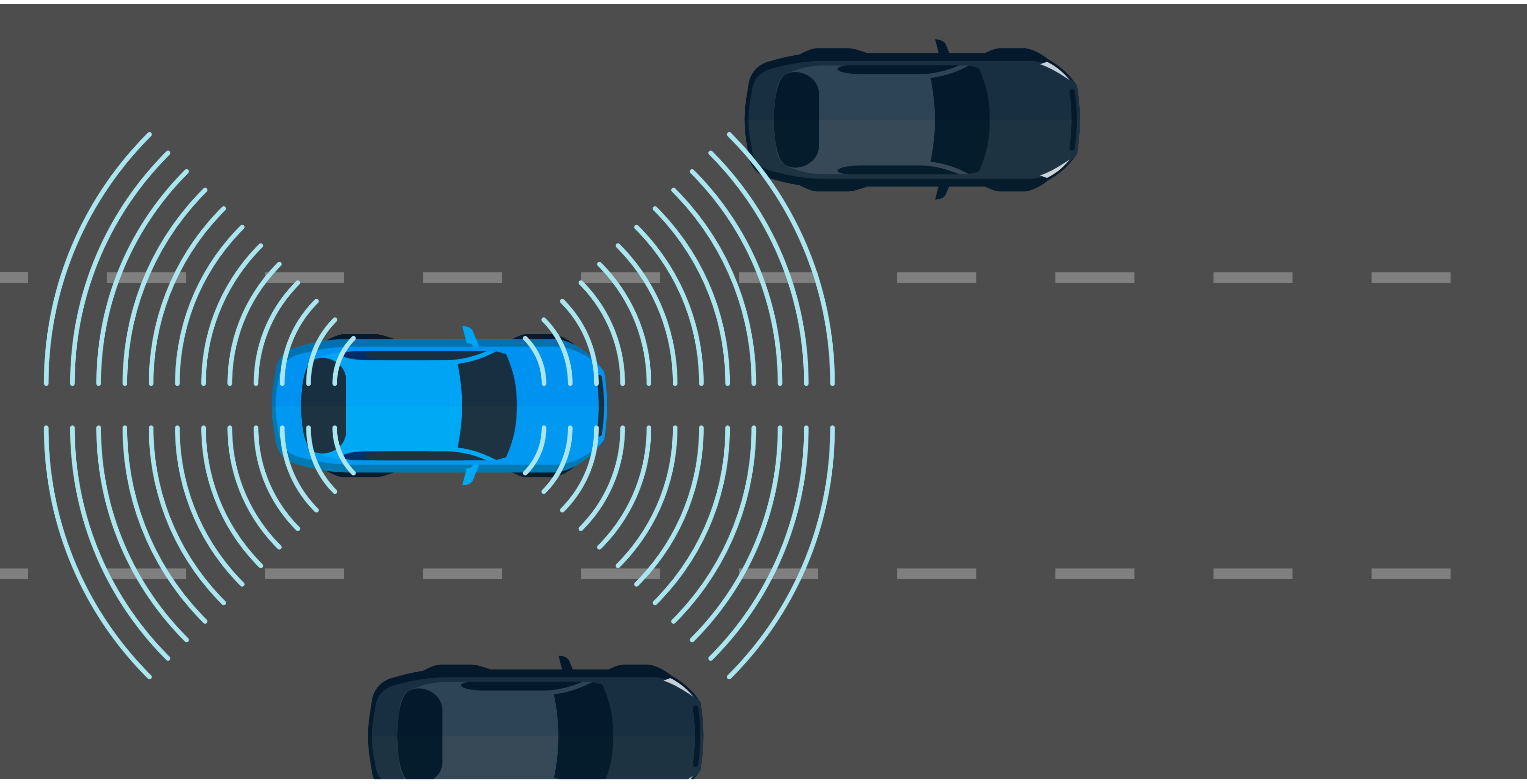



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**The current whirlwind** of disruptions buffeting the automotive world have created a massive value-chain disconnect. When viewed through the lens of tomorrow's product requirements, one thing becomes clear: you can't easily get there from here.

McKinsey has identified four major disruptions facing the industry today (Exhibit 1). Collectively known as "ACES"—for autonomous vehicles, connected cars, electrification, and shared mobility—these trends will ultimately drive a change in the way the automotive industry develops cars (see sidebar "ACES: The four trends shaping tomorrow's cars" for more detail).

By 2030, though, the ACES will dominate, and we'll see developments that may be as profound as those that emerged when the automobile was invented. The characteristics of mobility at the second great inflection point will be significantly, not just marginally, better. The industry's focus will move away from past differentiators, such as powertrains, and concentrate on the car's embryonic technology stack—a term borrowed from the technology industry that describes the layers of software and hardware that comprise a vehicle's operating system. As a result, the industry will shift from linear value chains with OEMs at the end of the assembly line to networked ecosystems with multiple players interacting with each other and the end consumer. New customer interfaces and services, as well as a dramatically different competitive landscape in which tech giants, start-ups, and OEMs mix and mingle, are just a few of the shifts in store. Radical improvements in cost effectiveness, convenience, experience, safety, and environmental impact will, taken together, disrupt myriad business models on an almost inconceivable scale.

Furthermore, enabling the new use cases the four ACES trends promise will require significant investments in new capabilities, such as network infrastructure, data-management platforms, and edge-computing power. This article will explore the underlying technological challenges facing the automotive industry in the ACES era and describe the roles different players can take in shaping an ecosystem to solve these challenges. We will also discuss why collaboration and partnerships across traditional industry boundaries will become more important than ever.

## 'ACES': The four trends shaping tomorrow's cars

**We believe tomorrow's cars** will be autonomous, connected, electrified, and shared (ACES). They will be fully *autonomous*, with no driver. The car will communicate with traffic-management cloud solutions to receive traffic updates and to download the latest high-definition maps. It will also communicate with other cars to gain the latest information on slippery roads or potholes.

Cars will become more *connected*, thus enabling a variety of use cases. In-vehicle media streaming is becoming common practice and will require mobile-network operators to build high-bandwidth network solutions across highways and in city centers. Positioning-based services will allow drivers to search digitally for nearby parking and find the most affordable gas stations in the area.

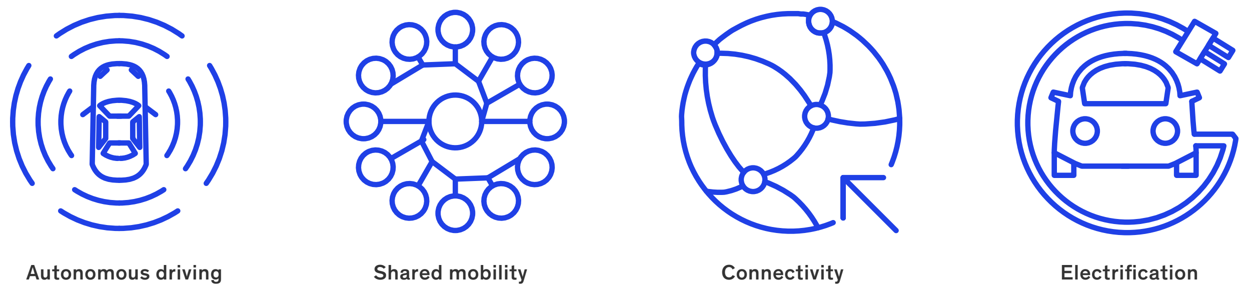
Additionally, cars will increasingly feature *electric powertrains*, which in addition to reducing emissions, will enable the cars to connect digitally and perform remote operations, such as over-the-air software updates, without having to fire up an internal combustion engine.

What's more, as part of the trend toward *shared mobility*, tomorrow's car will have multiple users. Consumers will be able to monetize their idle cars, and taxi companies of the future will be able to operate fleets of autonomous shuttles that have sophisticated route-optimization solutions and that have real-time updates based on traffic conditions and congestion patterns.

Exhibit 1

## Four trends will change the way the auto industry develops cars.

**4 "ACES" trends**




### The new automotive technology stack

The car of the future will feature lots of high technology, and in-vehicle systems as represented by connectivity comprise only one layer in the technology stack required to enable ACES. Many technical challenges remain across the stack, including many interdependencies (Exhibit 2). A review of some of the key issues follows.

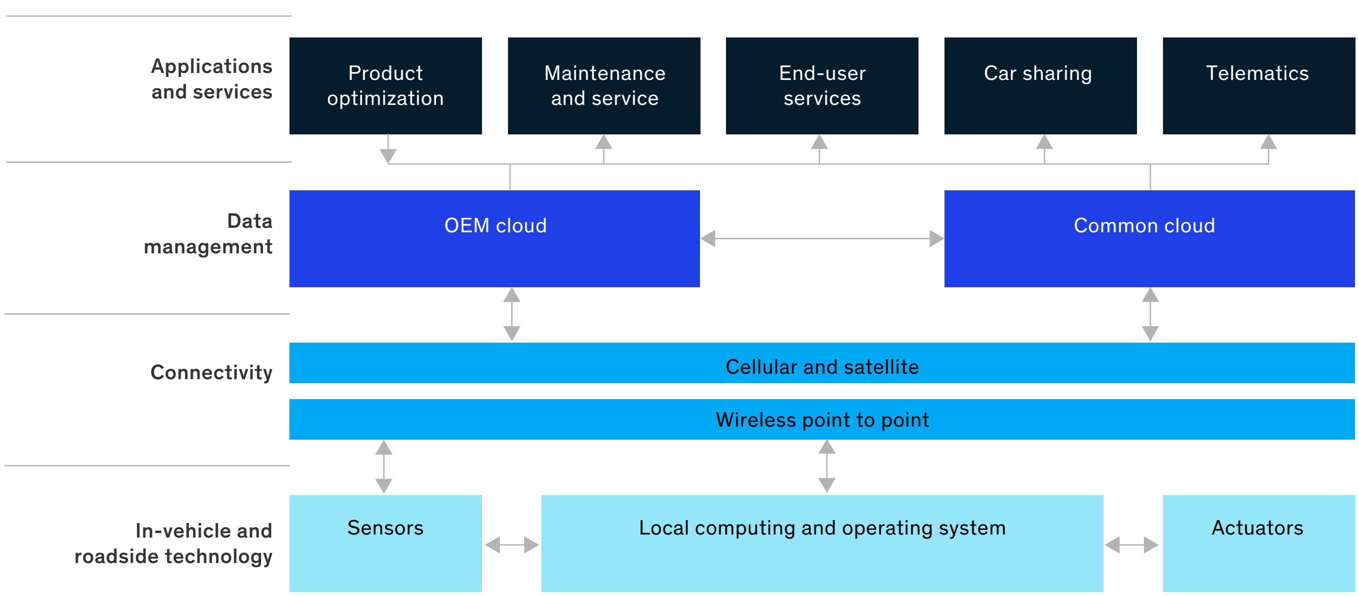
**In-vehicle and roadside technology**

We see a continuing trend to integrate car functions and related electronic control units (ECUs) into central domain controllers, with premium OEMs leading the technological push toward more integrated and connected infotainment systems. Moreover, the number of applications has increased significantly as the industry moves toward a service-oriented architecture with interdependent services.

Exhibit 2

## Automotive tech-stack challenges extend far beyond connectivity.

**Key issues in automotive tech stack**



We have also noted a significant spike in the number of in-vehicle sensors. The next two to three vehicle generations will feature sensors with similar functionalities to ensure functional safety through redundancy. In the long term, however, some OEMs might opt for more intelligent sensor solutions to reduce the total number of sensors and costs. Some sensors will also become more intelligent as computing power migrates from ECUs. In the future, such sensors can preprocess data for simple calculations, trigger actuators directly, and inform ECUs retrospectively about their actions.

In addition to making the car itself more connected, stakeholders need to build roads and infrastructure capable of supporting the car of the future. We envision a multitude of connected "devices" along the roadside, including cameras to monitor traffic situations, sensors to gauge temperature and driving conditions, temporary roadwork signs, and so on. All these devices will have to communicate—with cars as well as central intelligent traffic-management systems. While some of these devices will have a fiber connection and a reliable power source, many will rely on wireless links and battery power.

Telecom operators have a role to play to build networks with wide coverage and low energy requirements, based on narrowband Internet of Things, Cat M1, and soon, New Radio (NR). What's more, as telecom operators expand their capacity along highways, many synergies should emerge in sharing basic infrastructure, such as fiber-optic and power networks as well as civil work coordination.

**V2X connectivity**

Most cars already allow customers and OEMs to monitor, and to some extent, interact, with their vehicles. As we move toward an increasingly autonomous future, many use cases will rely on this connectivity and thus increase the need for wireless capacity and reliability. What's more, cars are likely to communicate with one another and the surrounding infrastructure, for example, to warn others about traffic incidents or poor road conditions. While OEMs are designing their autonomous vehicles to work without constant connectivity, there will be situations in the short- to midterm where remote, manual operations are required. For example, we already see some commercial vehicles capable of traveling long distances without a driver—trips that include remote operations directing the last mile to their destinations. Remote control requires ubiquitous and reliable networks in city areas with high bandwidth to transmit high-definition video, with low latency to enable smooth control. Overall, current communication infrastructure is not reliable enough for mission-critical applications. For instance, networks and direct communication systems lack the capacity to manage data traffic from fleets of autonomous cars communicating with one another in real time in dense urban environments or along crowded highways.

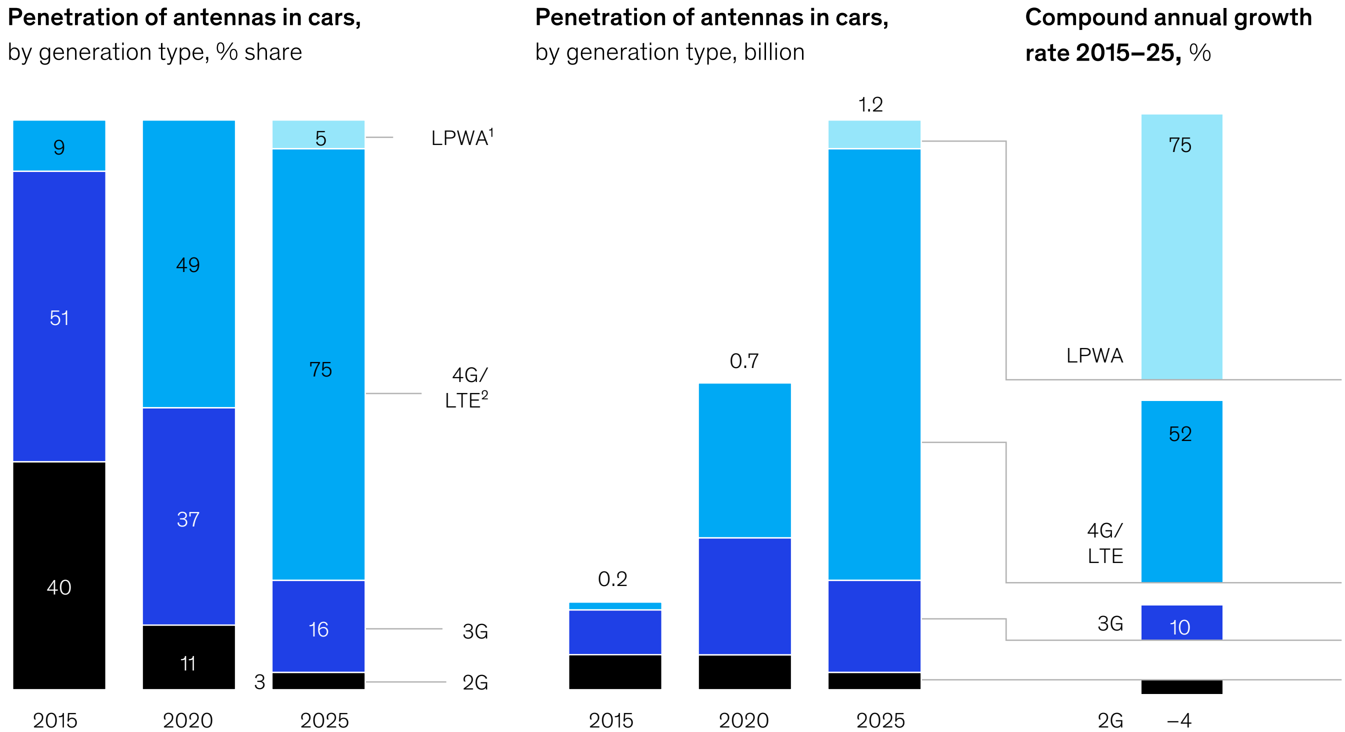
Moreover, Intel has estimated that a driverless car will generate more than four terabytes of data per day. While most of that will be processed in the car, there can be significant value created through sharing these data with other cars, the surrounding infrastructure, and the mobility ecosystem. The explosion of data transmission drives the need for higher speed and bandwidth, and, in turn, the penetration of antennas in cars (Exhibit 3).

The connectivity requirements for the car of the future largely involve two types of communication: network-based communication and direct communication.

**Network-based communication** allows cars to use the cellular network to communicate with nearby vehicles, pedestrians, and the infrastructure around them. Known as vehicle-to-network (V2N) communication, it has a much larger range of communication compared with direct methods. V2N employs mobile-network operators' (MNOs) commercially licensed spectrum, with access to cloud-based services and additional security offered by mobile networks.

Exhibit 3

## Increased data transmission could lead to a big uptick in car antennas.




[1]Low power, wide area.
[2]LTE = long-term evolution, a standard for high-speed wireless communication.
Source: Gartner; McKinsey analysis

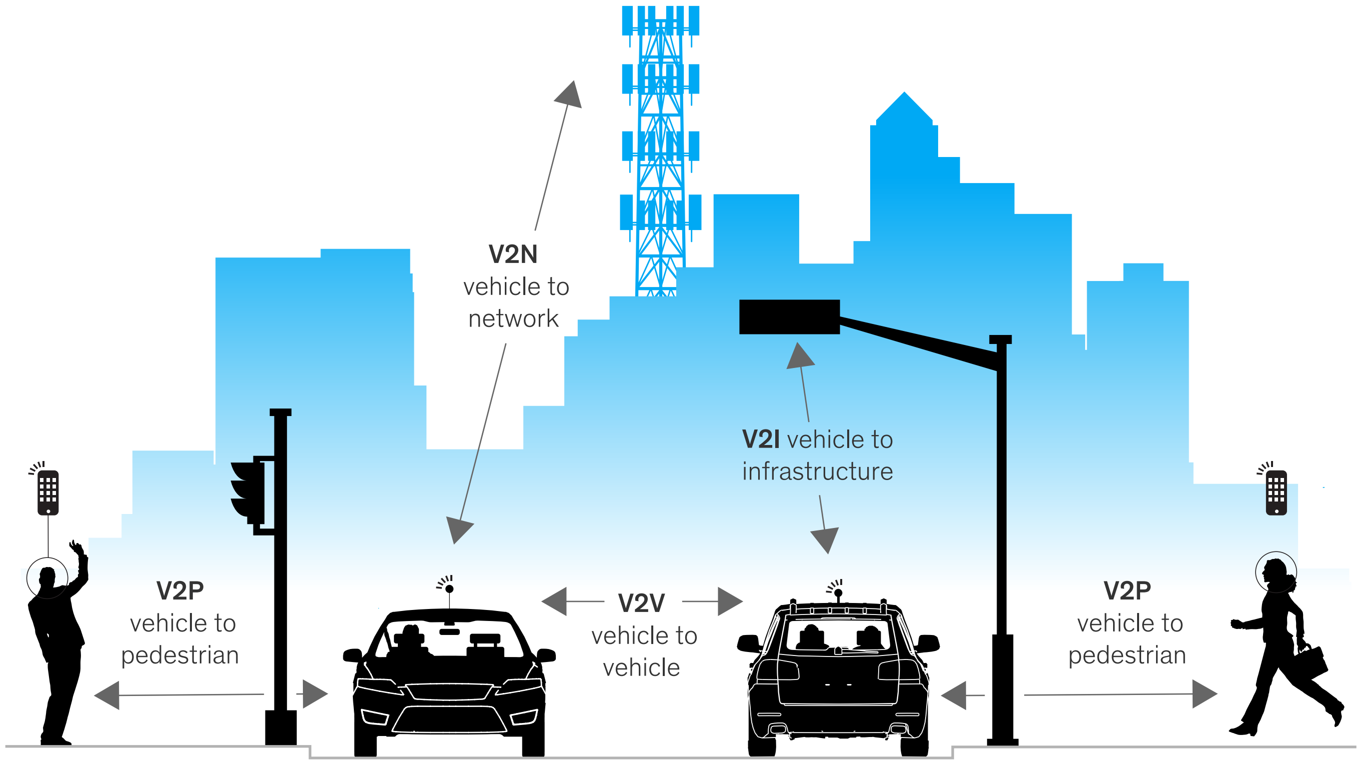
**Direct communication** enables vehicles to communicate directly with their nearby surroundings without relying significantly on cellular networks (Exhibit 4). This type of communication includes vehicle-to-vehicle (V2V) communication, where vehicles communicate with one another to issue warnings, avoid collisions, or share immediate road and traffic conditions. It also includes vehicle-to-infrastructure (V2I) communication, where vehicles communicate with nearby infrastructure, such as traffic lights, road signals, and other transport infrastructure to further strengthen safety measures. For instance, a traffic light may alert the vehicle that it is turning red and the vehicle should adjust its speed. The last form of direct communication includes vehicle-to-pedestrian (V2P) communication, where the vehicle communicates with devices carried by pedestrians to ensure their safety. For instance, such devices might warn the vehicle that a pedestrian is on the walkway ahead.

Direct communication uses the intelligent transportation systems (ITS) 5.9 gigahertz spectrum band dedicated for short-range communications and is not significantly dependent on the cellular network. The cellular network can, however, assist direct communication by expanding the range of communication in V2V, V2I, and V2P scenarios. The role of cellular networks in direct communication

Exhibit 4

## Ubiquitous connectivity can facilitate automation and autonomy among cars on the road.

**Direct vehicle communication**




becomes more relevant in non-line-of-sight (NLOS) systems, where the sensors on the vehicle may, for instance, not detect a nearby pedestrian and may instead receive alerts from the cellular network instead. Similarly, with cellular-assisted direct communication, an operator can rebroadcast a vehicle's report of hazards, such as road work, traffic accidents, or road blockage, to other vehicles beyond the range of direct V2V.

Regardless of the type of communication, ubiquitous connectivity is the key to facilitate automation and autonomy among the cars on the road. Direct communication helps to facilitate local coordination between cars where they communicate with their surroundings, for example, to adjust travel speeds to enhance safety. Network-based communication, on the other hand, facilitates autonomy at scale, providing the cars with up-to-date information about driving conditions and high-definition map data.

Fifth-generation wireless technology, or 5G, will be a key enabler of more reliable communication for vehicles, which will play a critical role in managing the safety challenges that come with vehicle automation and autonomy. There are multiple, often complementary technologies that can be used for both direct and network-based communications—including 4G/LTE, satellites, DSRC, and 802.11p.[1] 5G will significantly reduce latency and increase reliability compared with current technologies,

[1] 4G = fourth generation, LTE = long-term evolution, DSRC = dedicated short-range communication, and 802.11p addresses vehicular communication.

## Vehicle-to-network communication standards

**Dedicated short-range communication** is a higher-layer standard based on the IEEE 802.11p[1] Wi-Fi evolution. It is also the basis of a European standard for vehicular communication known as ETSI ITS-G5.

Cellular vehicle-to-everything communication (C-V2X) is a 3GPP-defined communication standard for using LTE and 5G NR for V2X communication. C-V2X was first specified as part of the 3GPP Release 14 in 2017 using 4G/LTE, and will further improve as part of Release 16 based on 5G NR.[2]

[1] IEEE 802.11p is an amendment to the IEEE 802.11 standard that addresses vehicular communication.
[2] 3GPP = third-generation partnership project, LTE = long-term-evolution, 5G NR = fifth-generation New Radio, 4G = fourth generation.

enabling new use cases such as trajectory sharing, real-time local updates, and coordinated driving.

Vehicle-to-everything (V2X) communication based on 5G—called 5G NR C-V2X—will support latency at ten milliseconds end to end (to and from the application layer) and one millisecond over the air. Similarly, 5G provides very high reliability, targeting 99.999 percent for ultrareliable transmissions. (For more, see sidebar “Vehicle-to-network communication standards.”)

A range of enhancements in the next-generation cellular technologies will be required to meet these extreme requirements on latency and reliability. First, enhancements in the physical layer of the 5G radio-access technology and network architecture will further improve latency and reliability. Second, active antenna systems (AAS) that integrate radio units with hundreds of antenna elements known as massive multiple-input, multiple-output (MIMO) antennas provide mobile operators the necessary hardware to boost network capacity. These antenna systems enable surgical beam–forming in the network, making it possible to schedule multiple users on the same frequency resources at the same time, hence increasing network capacity. Third, advanced network-orchestration features, such as network slicing, will allow more dynamic allocation of capacity in the network and cater for the massive scale of sensor communication.

**Data management and computing**

A secure data pipeline must aggregate the data generated by cars and road sensors, which cloud-based computers then analyze. Many automotive players are trying to build common platforms that will enable an ecosystem of connected vehicles and emerging services, such as location-based marketing, intelligent driving, and map creation or enhancement, with real-time data. We also see increased use of cloud capabilities to combine in-vehicle data with environmental data. Data that are neither safety critical nor personal will increasingly go through cloud-based processing to derive additional insights.

What’s more, enormous amounts of data require aggregation and processing to enable more advanced use cases, which will put significant stress on network capacity and latency. Distributed processing offers one potential solution to this challenge. Also known as edge computing, it manages local actions near the car and filters data before forwarding to central data centers for aggregated analysis. The Automotive Edge Computing Consortium advocates this solution and claims significant system-level benefits compared with traditional centralized cloud setups.

In another recent development, some consortia have begun to define standard application programming interfaces (APIs) for consuming common data and building new services on top of the platform.

**Applications and services**
The proliferation of sensors generating new streams of data and improvements in connectivity is enabling arrays of new applications and services, including more efficient car sharing, location-based advertising, and in-car delivery, which can create new value pools. These applications will require new application platforms capable of real-time analytics and strong integration with the hardware generating the data. Moreover, many applications will enable interactions across the ecosystem involving consumers, OEMs, and third parties, such as insurance companies or service providers.

While automakers hold the keys to unlock this value, many lack the capabilities and talent in crucial areas such as cloud-based app development, data management, and machine learning. In addition, many players struggle to build successful business models around data—largely due to organizational reasons. No player has all the access, assets, and competence required to build these applications alone. Rather, these new value pools will require a network of players.

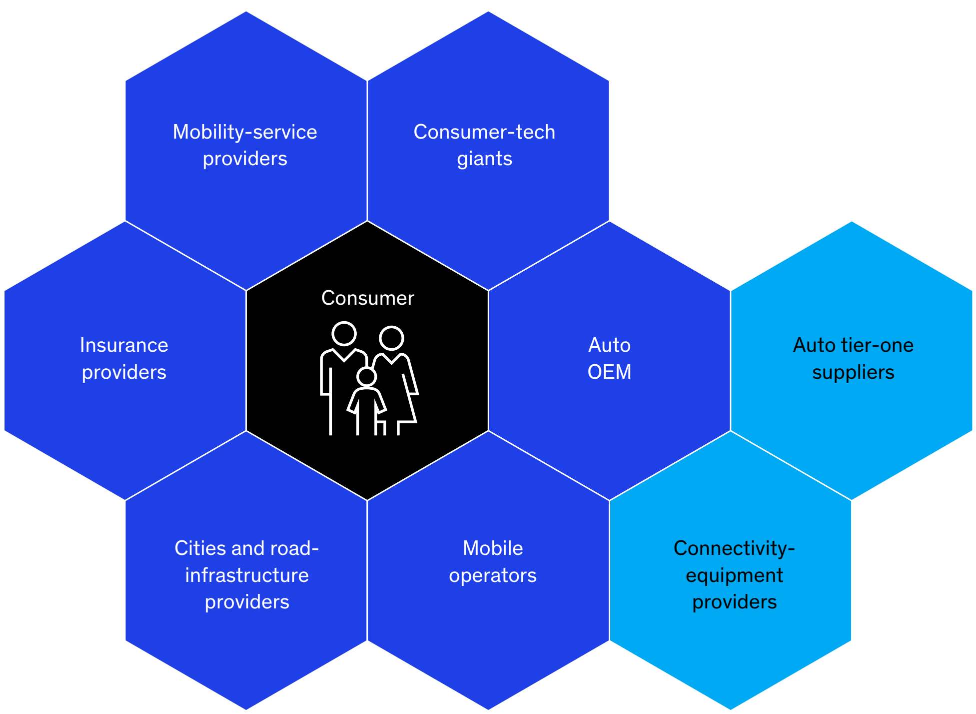
## Forming a new mobility ecosystem

OEMs have traditionally worked hand in hand with tier-one suppliers, but today we see the emergence of a broader ecosystem (Exhibit 5). This ecosystem is coalescing as high-tech players enter the market, incumbents form new partnerships, and tier-two suppliers cut in line to offer products and services directly to OEMs, thus bypassing tier-one companies. By our analysis, an OEM would have to invest nearly $75 billion to gain a defensible position across the critical technologies of autonomy, connectivity, electrification, and shared

Exhibit 5

### A new automotive ecosystem is beginning to coalesce.

**The new automotive ecosystem**



mobility. While the new technologies will doubtless generate enormous value, no one can say where the economic profit will flow—or when.

Automotive OEMs currently have control over the end customer (to a certain degree) and also the most important control point in the industry—the car itself. However, to stay relevant in an ACES world, automakers must reevaluate their roles in the ecosystem, understand where the control points will be in the future, and decide how much of the pie they are willing to share to form a thriving innovation network. In addition, OEMs must solve several technical challenges that include expanding software complexity, greater security issues, and more complicated connectivity-management responsibilities. Can any OEM tackle these challenges alone?

Mobile-network operators will likely move beyond offering pure connectivity to justify the increasing investments required. They have a strong starting position to offer local services such as parking, and multinational organizations that offer truly global solutions and services could easily capture a larger share of the pie.

For telecom-equipment manufacturers, these new ACES-inspired use cases will fuel the need for further investments in both networks and connectivity devices. There is also an opportunity to sell directly to new potential customers, including automotive OEMs and road-maintenance players. These use cases and customers will require tailored systems and solutions spanning the entire technology stack, including network access, connectivity devices, data management, and applications.

For global tech giants, the ACES car presents a major opportunity to disrupt yet another industry. They have already made their first industry beachheads, with several cars now using infotainment platforms from these players, and they have several ongoing projects to create new applications and services on top of the platform. Smaller tech start-ups are also trying to create a space for themselves in the automotive ecosystem, and we see increasing activity in this space. Moving forward, the tech players are first in line to take advantage of the increasing amounts of valuable data generated by cars. Both tech giants and start-ups are well situated to help automakers make the transition to technology-driven companies, which OEMs desperately need to make.

Finally, we see governments and large cities playing a more active role in shaping the ACES ecosystem, both by providing the crucial roadside infrastructure needed, and through investments in consortia to build open platforms for capturing and sharing data at scale.

## What are the key questions to address?

It remains unclear which players will win in this new high-tech automotive battlefield. We can, however, explore several questions.

**Who will invest?**

Automakers will likely look to mobile-network service providers for further investments in network performance to achieve higher service quality, increased predictability, lower latency, and greater bandwidth. The business case for making these investments is at best neutral, given current revenue models. Overall, 5G will become an important enabler for meeting the auto industry's growing network-quality and coverage requirements. Likewise, the rollout of new technologies, such as beam forming and network slicing, should help resolve communication issues, as should the new frequencies up for auction around the world. Such support will come a cost, however, further stressing the need for forming ecosystems to unlock new value pools.

We might also see an increase in public–private partnerships to address some of these issues, including among cities and transportation agencies, which could co-invest with both telecom operators and automakers to build the necessary network infrastructure.

**How will the ecosystem manage data?**
As the proliferation and volume of data sources increase, questions arise as to who will control the end-to-end flow of data and to who has the right to use what data. The proliferation of data also generates questions regarding regulatory concerns. Data security will be of paramount concern throughout the ecosystem and across the entire technology stack, so who will be accountable for leaks or misuse? Furthermore, will players attempt to resolve these issues on a country-by-country, regional, or global basis?

**What are the emerging business models?**
In addition to using data to optimize the driving experience, the industry must determine who will own and have the right to monetize the data and create new value pools. Will the OEMs control the customer relationship in a traditional business-to-consumer model? Or, we might see neutral parties playing intermediary roles in the ecosystem as they manage data transactions?

Telecom operators are also looking for ways to capitalize on the rise of connectivity beyond the traditional mobile-broadband subscription models of today. Will they partner with automakers as end-to-end technology suppliers? Should they approach cities and governments to help fund the infrastructure? Can they monetize the data by providing insights to insurance providers and city planners? ACES stakeholders need to work through these and many other questions concerning this new ecosystem, recognizing the fluid nature of the industry at this point, and how future changes could expose company weaknesses or reveal new opportunities.

**What role can regulators play?**
If managed right, the car of the future can unlock significant societal value and innovation for many years to come. Regulatory bodies should consider how to support automotive OEMs and mobile-network operators in shaping the ecosystem and becoming leaders in their respective markets. Possible activities include encouraging investments, facilitating trials, and providing the needed frequencies. At the same time, regulators might also advocate for a diverse and competitive landscape that is technology neutral, instead of betting on a single solution.

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The ACES trends represent a new wave of automotive innovation that connects the car with its environment in new, more efficient and effective ways. As such, they present difficult development challenges and are attracting a wide range of new players to the industry that many incumbents might not be ready to accommodate. Perhaps the biggest problem faced by incumbents and other players is the need to join or create stable ecosystems that can enable them to ride this wave, even as the tide goes out on the industry's old ways of doing things.

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