molex

TECH BRIEF

Ubiquitous Connectivity and the Vehicle of Tomorrow

creating connections for life

The Importance of Connectivity

In the past, connectivity on the road was always intermittent. Whether the connectivity failure was due to losing a radio signal in a tunnel or a dropped cellular signal in a remote area, drivers were accustomed to wireless signals only following them to a certain point. But as technology improves and vehicles become increasingly connected to the world around them in a variety of ways—and for a variety of purposes—maintaining ubiquitous connectivity is increasingly crucial.

Tomorrow's vehicles will offer immense functionality thanks to vehicle-to-everything (V2X) connections, including vehicle-to-network (V2N) connectivity. These benefits will include enhanced safety and comfort, navigation aids, security, entertainment and machine health. Vehicle design must support the reliable and continuous operation of these functions and meet the demands of drivers and users who expect them to be available when needed. Losing connection will no longer be an acceptable and anticipated part of driving. Manufacturers are well aware that reliable connectivity is vital to ensuring customer satisfaction.

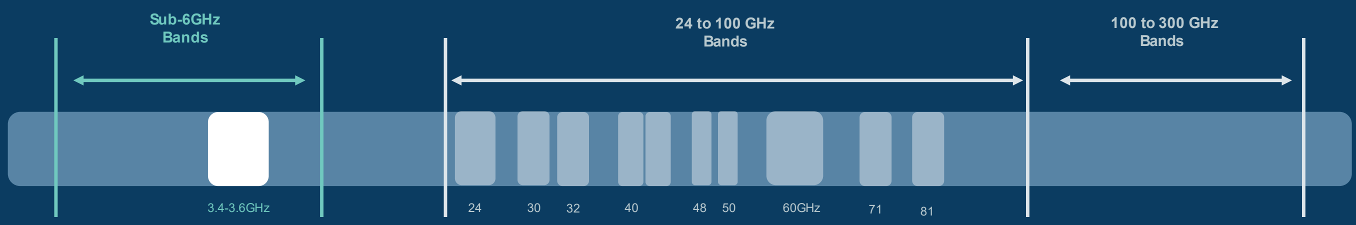
The technical challenges of maintaining full-time connectivity vary considerably based on where the vehicle is. In areas with cellular coverage, network connectivity may be available but not at sufficient speed to enable full functionality. In rural, remote or mountainous areas, coverage gaps in cellular networks lead to a complete loss of connectivity. At the other end of the spectrum, in dense urban centers or areas with a high concentration of devices such as airports or traffic jams, the network may be unable to meet the demands of so many users. Addressing these challenges to provide ubiquitous connectivity means developing an array of electronic solutions.

Varied Challenges and an Array of Solutions

Connectivity: Maximizing Performance

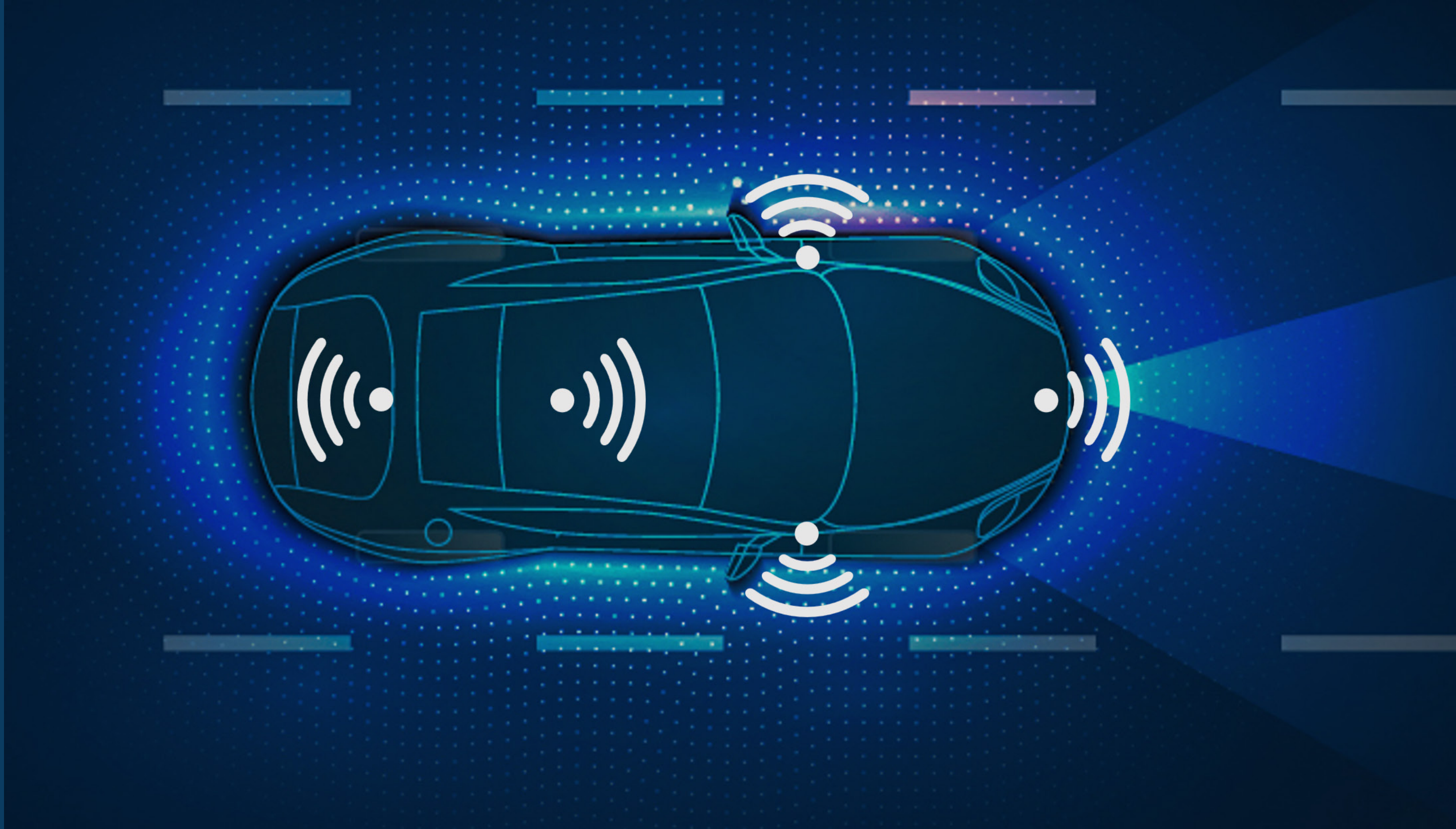
Most vehicle miles driven today are in areas covered by the terrestrial network (TN) of cellular connectivity—this is how vehicles connect to 4G or 5G systems. The challenge for future vehicles will be optimizing the data rates available to support V2X and V2N connectivity for all the vehicle's systems. The solution is to employ 5G FR1 multiple-in multiple-out (MIMO) technology.

The goal of MIMO is to turbocharge cellular connectivity. The FR1 frequency band of 410 MHz to 7.125 GHz permits optimized high-speed 4G and 5G performance. With MIMO technology, tomorrow's vehicles will be able to minimize errors, optimize data speeds and improve the capacity of wireless transmissions by enabling data to travel over multiple signal paths concurrently. Utilizing MIMO to create multiple copies of the same signal offers additional opportunities for the signal to connect with the receiving antenna without being affected by fading. This capability can improve the signal-to-noise ratio and reduce the error rate.



MIMO boosts the throughput of radio frequency (RF) systems and creates a connection that is more stable and less congested. To enable this, the electronics architecture of the vehicle must incorporate several different antennas at different points throughout the car. This vehicle distributed antenna system (vDAS) architecture consists of multiple antennas connected via an analog or digital interface. In future implementations, the interface will be digital.

The signal quality and speed offered by 5G FR1 MIMO in areas with cellular coverage will enable increased levels of communication and a broader range of functions found in tomorrow's vehicles. vDAS architecture allows this capability to be designed into the vehicle and enables antenna technology that is targeted to address capacity challenges.



Closer Look: Vehicle Distributed Antenna Systems (vDAS)

For optimized connectivity both inside and outside the vehicle, a new approach to how vehicle architecture and antenna design interact is necessary. Placing antennas at different points throughout the vehicle to maximize effectiveness and synergistic effects is the goal of the vehicle distributed antenna system, or vDAS. vDAS can include several different types of antennas to accomplish different objectives: 5G 4x4 MIMO antenna arrays, blade antennas and shark-fin antennas for V2X and cellular communications, Global Navigation Satellite System (GNSS) antennas for navigation and radio antennas for simple radio reception, plus Wi-Fi and Bluetooth low-energy (BLE) antennas for connecting to devices within the vehicle.

Many of these products are custom-designed for specific vehicles and applications. A 5G 4x4 MIMO system may use two blade antennas and a shark-fin with two cross-polarized antennas. An example of a 5G mmWave system might use phased antenna arrays at 75 degrees at the front and rear of the vehicle, with flat arrays on either side. Antenna arrays for satellite communications, capable of beamforming and steering using a central processor, are also distributed around the vehicle.

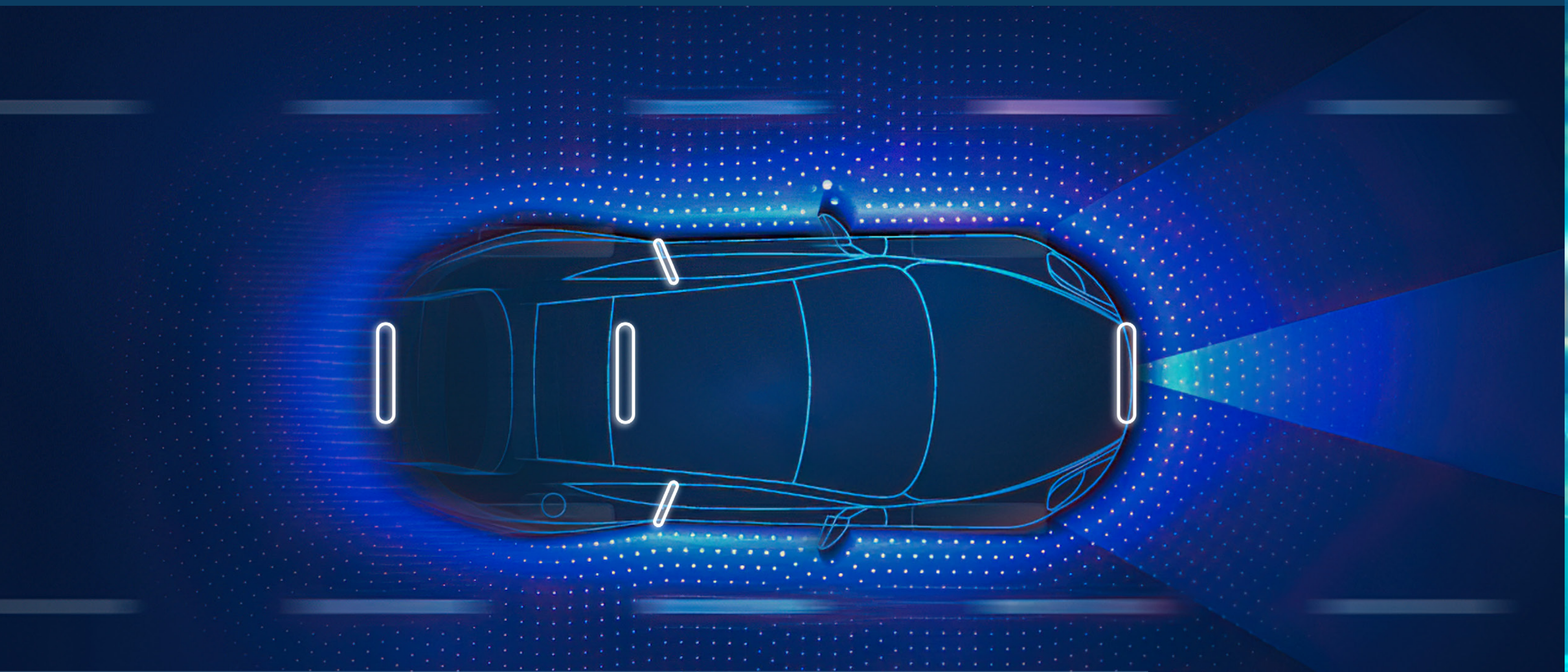
Common locations for mounting antennas include on the vehicle roof, on the windshield, on the instrument panel for in-vehicle communications, or embedded in the spoiler or front fascia. Hidden and conformal antenna solutions are additional options that blend into the car body to enable smooth vehicle designs and uncluttered aesthetics. Vehicle architecture plays a major role in addressing the potential complexity of vDAS wiring. With a multitude of devices at different points in the vehicle and the need for a processor for the control or steering loop for beamforming antennas, digital interfaces offer savings in materials, space and installation costs. Zonal architecture can further simplify vDAS implementation.

Capacity: Network Access in Dense Environments

Cellular network coverage in densely populated areas like urban centers, and in locations such as airports, sports venues and roads subject to traffic congestion, is nearly universal. The challenge in these areas is not coverage—it's capacity. With current levels of connectivity and current network speeds, vehicles can lose service even when there is a cellular signal available because the network is overloaded.

In these densely developed and occupied environments, the solution is 5G mmWave technology. This system utilizes the large 5G FR2 frequency bandwidth available between 24.25 and 52.6 GHz. In congested conditions, mmWave technology provides speeds that are 4 to 5 times faster than low- or mid-band of FR1, enabling significantly better performance and network utilization. Increasing data rates, reducing latency and closing TN coverage gaps can all be accomplished, even under heavy network loads, through the use of mmWave technology. One limiting factor is the operating range, which is limited to less than a kilometer, but in urban areas, this is acceptable.

Enabling the vehicle to utilize mmWave connectivity requires precisely aligned antenna arrays. These arrays utilize digitally controlled beamforming tracking and steering to improve signal reception and help cancel out interference. Beamforming involves focusing and directing the signal beam by changing the phase of the input signals on the radiating elements in the array. With this capability, the effective range and signal integrity can both be improved. Beamforming requires high-speed interfaces and high-performance signal processing capability within the vehicle to create a control loop that can regularly monitor and adjust the beamforming setting to optimize performance and signal strength.



mmWave phased array antennas utilize a miniaturized form factor with scalable, modular variants available for mounting in different areas of the vehicle. With digitally controlled beamforming technology, vehicles will be able to maintain constant high-speed connectivity even in crowded urban areas.

Closer Look: Beamforming and Beam Steering

Beamforming involves the use of multiple radiating elements in an antenna to focus and direct—or form—the signal beam. By changing the phase of the input signals on all the radiating elements, the main lobe of the beam can be focused to increase the signal range. This also helps cancel out interference in crowded urban areas with high densities of individual user equipment (UE).

Beamforming and beam steering require electronic control and onboard signal processing capability. There are three options for the interface: analog, digital and hybrid.

Analog beamforming changes the phase of the signal in the analog domain. A single RF transceiver output is split into several paths served by different antenna elements, with a phase shifter and amplifier modifying each signal before it reaches the antenna element. The disadvantage is that analog beamforming can only handle a single data stream and generate one signal beam at a time, limiting its use with 5G, where multiple beams are necessary. It also requires additional component and cable space.

In digital beamforming, each signal is pre-coded (with amplitude and phase modifications) in baseband processing before RF transmission. Each antenna element has its own transceiver and data converter, enabling several sets of signals to be superimposed on the antenna array elements simultaneously. This enables a single antenna array to serve multiple beams and, hence, multiple users, which is ideal for 5G networks. It also permits digital methodology to replace traditional trial-and-error methods of beam tracking.

Hybrid beamforming offers a compromise between the flexibility of digital beamforming and the lower cost and power consumption of analog beamforming. This system conducts analog beamforming in the RF stage and digital beamforming in the baseband.

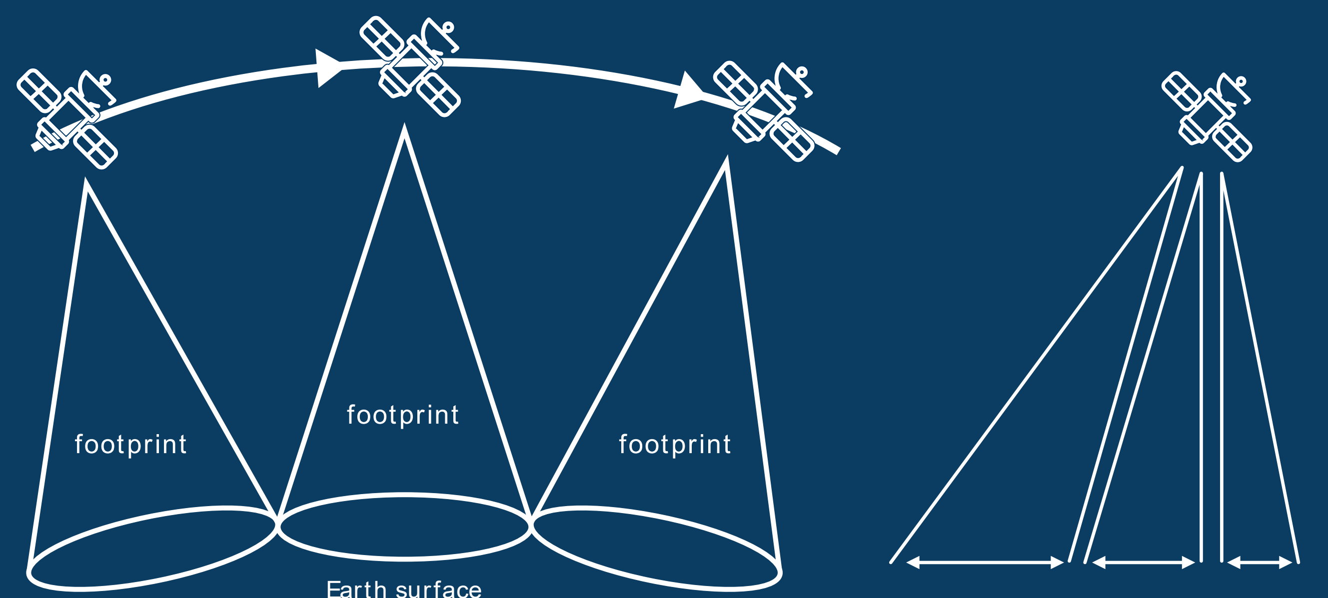
Overall, digital beamforming permits faster and higher-capacity beam tracking and steering. This facilitates the use of mmWave and non-terrestrial network (NTN) 5G connectivity and is a primary enabler of ubiquitous broadband connectivity for vehicles.

Coverage: Eliminating Network Gaps

For truly ubiquitous connectivity, network coverage must be expanded beyond the reach of existing TN capabilities. The solution to this challenge is the non-terrestrial network (NTN) that offers a broadband satellite-based connection. NTN satellite communication systems can provide coverage for hundreds of kilometers, making connectivity available in rural and remote areas as well as in challenging environments like deserts and mountain ranges. They can also be indispensable during public safety emergencies where TN communications are affected.

NTN provides two aspects: NTN-IoT (Internet of Things), with a narrow band and low data rate or wideband offering enhanced data rates, and NTN-NR (New Radio), with broadband access. NTN-NR offers the potential for fast, reliable and efficient wireless access in remote areas.

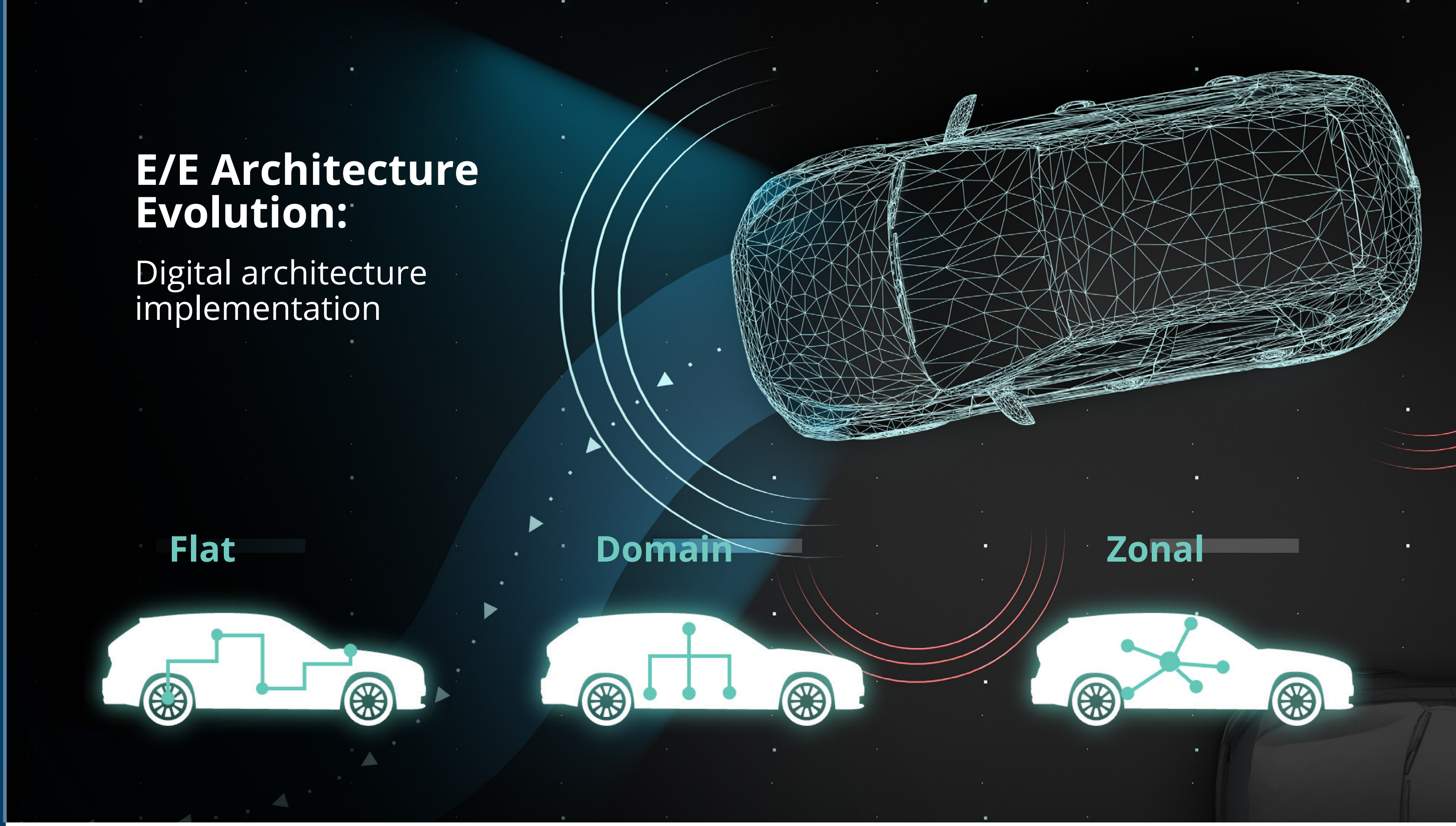
NTN-NR relies on beamforming antennas to maintain optimal performance by improving the signal-to-noise ratio and reducing interference in crowded environments. Communications satellites move overhead in orbit, creating a "constellation" of signal sources that is always moving overhead. As each satellite moves relative to the Earth's surface, the beamwidth changes along with the elevation angle. Onboard the vehicle, beamforming and steering—digitally controlled through the use of a control/steering loop—works to adjust to the changing beamwidth.



Low earth orbit (LEO) constellation, satelites / beams are moving

Beamwidth changes with the elevation angle

NTN connectivity is not without its challenges. It relies on line-of-sight visibility to the satellite, which is an issue when the satellite is just above the horizon. The constant movement of the satellite also creates a Doppler effect that can lead to high shift and high variation rate. The signal amplitude and phase can also experience rapid fluctuations due to atmospheric and weather-related influences. But with sufficient satellite coverage, NTN communication can offer high data speeds to enormous areas that aren't included in TN coverage.



Vehicle Architecture and Antenna Systems

With available solutions addressing connectivity, coverage and capacity challenges, manufacturers need to integrate these solutions into the vehicle in a cost-effective and efficient manner. A series of different antennas mounted throughout the vehicle, along with the processors required to operate the system, present a challenge due to the number of components that need to be packaged and fitted to the car body and incorporated into the wiring architecture.

As the number of electronic devices in vehicles increases, vehicle electrical/electronic (E/E) architecture is undergoing a transformation from a domain-based system to a zonal system. Zonal architecture simplifies cabling and lowers wiring harness and installation costs by dividing the vehicle into zones, each with its own zonal controller. Individual devices, such as antennas, can be connected to the nearest zonal controller rather than all devices being connected back to the central processing unit.

This change in vehicle architecture requires digital rather than analog interfaces between devices and controllers. Digital interfaces have multiple advantages over analog counterparts: loss-less RF signal transmission, less expensive harnesses, and smaller space requirements, with thinner signal cables replacing heavy coaxial cables. Using digital interfaces permits the installation of more antennas around the vehicle, permitting vDAS implementation without adding an unacceptable amount of weight or wiring harness complexity.

Synergies and Integration Opportunities

As an innovator in vehicle antenna and connectivity solutions, Molex is uniquely positioned to combine its expertise in multiple fields and industries to create integrated solutions. Molex is already a global leader in shark-fin and blade antennas for 5G TN connectivity. Additional solutions, such as mmWave antennas, offer opportunities for Molex to leverage synergies with its consumer products to improve the robustness and compactness of designs. These components are being followed by additional solutions, such as 5G FR1 4x4 MIMO arrays, NTN satellite broadband systems and beamforming technology, that are designed to foster ubiquitous connectivity.

Automotive architecture is another field in which Molex is working to enable innovative vehicle antenna solutions. The MX-DaSH line of hybrid connectors is designed to foster the transition to zonal architecture, offering digital, signal and power connectivity between a central processor and zonal controllers in a single combined connector. This capability simplifies wiring while adding digital interface functionality and is crucial to vDAS design. Building these abilities into vehicle wiring design at this stage also helps to future-proof vehicles for additional connectivity capabilities currently in development.

Molex engineers are working with industry associations like the 5G Automotive Association (5GAA) and 3rd Generation Partnership Project (3GPP) to establish standards for 5G FR1, 5G FR2 and NTN vehicle communications that will enable the development of the infrastructure necessary for these technologies. These standards are crucial to implementing the solutions needed for truly ubiquitous connectivity.

Closer Look: Molex Antenna Solutions

Molex offers custom antenna solutions for any connectivity requirement, designed and tested to meet the exact specifications of automotive and commercial vehicle manufacturers. Our engineers employ industry-leading RF expertise to develop best-in-class antennas that ensure superior connectivity.

- **Connections:** GNSS, BLE, V2X, AM/FM, Cellular, SiriusXM
- **Mounting Locations:** Rooftop; in glass; spoiler; instrument panel; under glass; in roof; bumper; side mirrors; plastic trim
- **Antenna Types:** Smart antenna with integrated processor; shark-fin; low-profile; hidden; in glass; foil
- **Antenna Bands/Frequencies:**
  Cellular: 4G-LTE/5G MIMO; 617 MHz to 5 GHz; 1710 to 2170 MHz; 2496 to 2690 MHz; 3400 to 3800 MHz
  GNSS: GPS (L1, L2, L5); GLONASS (L1, L2, L5); Galileo (E1, E5b); Beidou
  AM/FM: AM, 535 to 1705 KHz; FM, 76 to 108 MHz
  DAB: 174 to 240 MHz
  SiriusXM: 2320 to 2345 MHz; Compliant to SXM03 specification
  V2X: 802.11p DSRC/C-V2X; 5.9 GHz
  BLE/Wi-Fi: 2.4 GHz
  RKE/TPMS: 315 MHz; 433 Mhz; 868 MHz
  Camera Function

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