



Challenge of verifying mission-critical Ethernet network performance in the car:

The benefits of time-sensitive network (TSN) simulation testing

Ethernet: an enabling technology for the next generation of passenger vehicles

The next wave of infotainment, safety and body electronics technologies to be deployed in the car offer highly attractive benefits to drivers, passengers, and even to other road users. Car manufacturers know that they can excite potential buyers by offering desirable consumer-friendly features and high-tech convenience and driver-assistance functions, such as:

- autonomous driving features such as camera- and radar-based highway lane-changing assistance
- surround-view parking assistance images in the center information display
- ultra high-definition display screens in the rear headrests

All these advanced features have one thing in common: the bandwidth requirement and data transmission rates are far higher than in previous generations of vehicles. Older automotive network technologies, such as CAN and MOST, were developed for these previous generations, and were never intended to support bandwidth-hungry applications such as streaming high-definition audio/video content or real-time ranging-sensor inputs.

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Abstract

This white paper explores the reasons why vehicle manufacturers are adopting Ethernet networking technology, and the challenges that manufacturers and their suppliers face in verifying the performance of Ethernet equipment when operating in automotive applications. It then outlines techniques developed in the ICT (Information and Communication Technology) industry for testing and verifying high-speed networks, and describes the ways in which dedicated network simulation instruments can help to achieve better test outcomes for developers of Ethernet components and networks designed for use in automotive applications.

The rapidly increasing quantity and speed of network traffic in the car poses several challenges to automotive manufacturers:

- **Latency**—in a modern brake-by-wire system, for example, the interval between the driver's press on the brake pedal and the actuation of the braking mechanism at the wheels must have an extremely short maximum duration. What is more, the data networking system carrying the signal from the brake pedal to the brake disc must be able to guarantee the interval between transmission and reception of the signal. But the car is a complex networked environment which simultaneously carries multiple types of traffic between hundreds of nodes. How is network capacity for low-latency signals such as braking instructions to be guaranteed?
- **Quality of Service (QoS)**—in the car showroom, the sharp, bright high-definition displays in the rear headrests might look impressive. But what will be the effect on the brand's reputation if, in ordinary use, the displays commonly suffer from picture break-up or buffering? To display a movie satisfactorily, a network must provide a continuous stream of data typically at a rate of several MB/s, without interruption. Again, in a complex and high-traffic network environment, data with QoS requirements must be able to take priority over best-effort data types.
- **Availability**—when safety-critical functions such as brakes, steering and lighting controls depend on commands transmitted over a network, the network itself is a safety-critical component. Network capacity must be guaranteed to be available whenever the vehicle is operating. In telecoms equipment, operators commonly require guaranteed 99.999% availability and redundant, hot-swappable network elements. In the same way, the safety of road users demands guaranteed availability of in-car networks.
- **Synchronization**—360° surround-view cameras stitch together inputs from multiple cameras on each side of the vehicle. These multiple inputs must be precisely synchronized in order to produce a single seamless image.

In the world of enterprise computing, the problem of bandwidth and speed has been solved by Ethernet. Today, the telecoms industry has a clear roadmap for the implementation of Ethernet equipment operating at data rates of up to 400Gbits/s. Automotive manufacturers today are implementing networks operating at a data rate of 100Mbits/s, with a roadmap to 1Gbit/s and then to multiple Gigabits/s, so Ethernet offers plenty of headroom for future growth in data traffic.

Ethernet is also attractive to the automotive industry because it is proven, benefits from a wealth of industry standards for a versatile mix of use cases, is supported by many component and systems manufacturers, and is backed by a comprehensive ecosystem of firmware and test solutions suppliers.

When implemented in a car, an Ethernet network also enables the use of simplified, lightweight cabling. Since traffic is routed via multiplexed, switched connections, the length of cable required to connect any given number of nodes in an Ethernet network is less than that required by the simpler point-to-point topologies supported by CAN or the ring topology supported by MOST (see Figure 1).

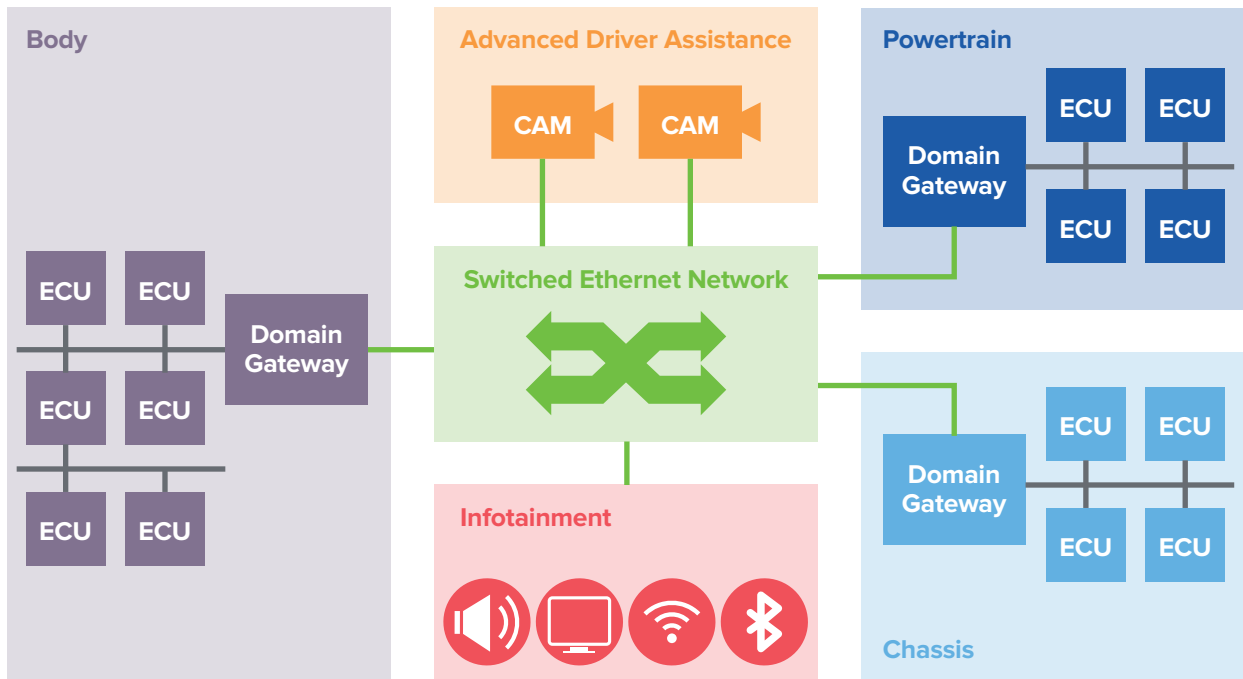


Figure 1: The switch-based architecture enabled by the Ethernet protocol provides for simpler cabling schemes than CAN or MOST support

But unlike enterprise computing applications, many applications in the car are time-sensitive and safety-critical: latency and synchronization must be guaranteed within strict limits. Natively, Ethernet does not meet this requirement. But by adopting the TSN – Time-Sensitive Networks – extension of the Ethernet protocol, automotive systems designers can meet all their requirements for latency, synchronization, availability and QoS.

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How the TSN protocol extension guarantees proper transmission of mission-critical data

The TSN enhancement to the Ethernet protocol was originally developed for use in professional audio/video (A/V) equipment, and was first known as the AVB (Audio Video Bridging) set of standards. The 'Time-Sensitive Networks' moniker was subsequently adopted after industrial equipment manufacturers started to adopt the technology.

The primary purpose of the TSN extension is to make the operation of an Ethernet network deterministic - that is, to ensure that high-priority packets are guaranteed to reach their destination within a known, maximum interval between transmission and reception.

Time-Sensitive Networking is comprised of a set of standards under development by the Time-Sensitive Networking Task Group, a section of the IEEE 802.1 standards group. Together, the set of TSN standards provides various elements of a deterministic operating framework for Ethernet networks. These include:

- QoS guarantees
- a network time synchronization service
- a related transport protocol for transmission of time-sensitive traffic

The operation of TSN systems depends on the application of a number of important concepts that are not native to the Ethernet standard normally deployed in enterprise networks.

'Network time', backed by rigorous specifications for latency, provides a network-wide clock by which the delivery of packets may be synchronized.

'Priority' allows for the distinction between data streams that are time-sensitive, and ordinary traffic that is transmitted on the conventional Ethernet best-effort basis.

'Reservation' is a way of allocating a certain quantity of guaranteed bandwidth, which is reserved for high-priority traffic.

The TSN standards also stipulate traffic shaping and forwarding rules, and provide standard methods for discovery, enumeration and control.

Above, this paper stated that new automotive network implementations had to meet the challenges of latency, QoS, availability and synchronization. The TSN standards enable all of these problems to be solved.

For ADAS sensors supporting a collision-avoidance function, for instance, system responses are measured in microseconds. Low latency and high availability for safety-critical signals such as these are supported by the TSN concepts of priority and reservation.

Likewise, the seamless display of 360° surround-view parking-assistance images requires the exact synchronization of video signals and data from multiple cameras and proximity sensors in real time. This is supported by the TSN concepts of network time and priority.

And when implemented with TSN technology, an automotive Ethernet network may benefit from the use of standards-compliant components and systems from a thriving ecosystem of suppliers. When produced in conformance to the Ethernet TSN standards, any one component should be interoperable with any other when used in an automotive network.

Implemented correctly, then, the TSN extension of Ethernet promises the performance and reliability that time- and safety-critical automotive applications require.

The question for automotive manufacturers is, how best to verify that a network element or an entire networked system conforms to the standard, and performs as required in all specified operating conditions?

Verification tests: how to be assured of conformance to the Ethernet TSN standards

While the TSN standard provides a technology framework for an automotive network for time- and safety-critical signals, the practical implementation is in the hands of the car manufacturer itself and its systems and component suppliers.

This network, like every other automotive component, will be subject to the full rigor of the car manufacturer's quality assurance, safety assurance and product testing regimes. But what should be the scope and purpose of the testing of Ethernet TSN equipment? What should the automotive manufacturer's test programs be designed to discover?

The Ethernet TSN set of protocols are published as open standards. This means that one key outcome of testing must be to verify that the component or equipment actually conforms to the standards. Conformance is important for two main reasons:

- first, it provides assurance that the device under test (DUT) meets the standard's minimum specifications for latency, availability and synchronization
- second, it provides assurance to users of the tested components or modules that they will be interoperable with any other conformant device

Conformance tests are standardized under the auspices of the Avnu Alliance (avnu.org). The Avnu Alliance is an industry consortium which facilitates the development of open standards and the certification of devices for time-sensitive networking. The conformance test cases published by the Avnu Alliance are recognized by the industry as providing the basis for verifying conformance to the Ethernet TSN standards.

To guarantee that the results of a conformance test program will be recognized by the automotive industry, device manufacturers need to use a test suite that is itself certified for TSN conformance testing.

Spirent is the automotive industry's leading provider of conformance test equipment for Ethernet TSN devices. Its Automotive AVB Conformance Test Suite Pack is based on the Avnu Alliance's test specifications, and provides a full suite of conformance tests for Ethernet TSN. Its coverage includes:

- the master standard, IEEE 802.1BA: Audio-Video Bridging systems
- IEEE 802.1AS: Timing and Synchronization for Time-Sensitive Applications (gPTP)
- IEEE 802.1Qav: Forwarding and Queuing for Time-Sensitive Streams (FQTSS)
- IEEE 1722: Layer 2 AVB Transport Protocol

The test suite runs on a Spirent TestCenter C50 test system, which also provides the capability to customize test scenarios, to extend the scope of the tests beyond the conditions specified by the Avnu Alliance. It supports negative testing, which allows the user to analyze the DUT's behavior when a network element fails or operates beyond its rated limits. Furthermore, it can generate mixed TSN and non-TSN traffic, and provide highly accurate and precise timing measurements.

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Performance testing: does the device or network behave in the way it is meant to behave?

Conformance with the specifications of the Ethernet TSN standards does not on its own guarantee the network's performance in all potential operating conditions.

While the Ethernet TSN standard provides resources to enable low-latency, high-availability network performance, the stress of operation in the real world could potentially impair the performance of a component, system or network.

In the automotive industry, a common method for verifying component or system performance is the drive test, which exposes the DUT to actual "on the road" conditions. For network performance testing, however, drive testing has severe limitations:

- the tester cannot precisely control the test conditions to which the DUT is exposed. In a drive test, a DUT will not necessarily encounter extreme or harsh operating conditions.
- the test conditions cannot readily be repeated or reproduced
- test parameters cannot be isolated and controlled. In the case of an observed impairment in the DUT's performance, a single cause will not necessarily be able to be clearly identified

Manufacturers of network equipment used by the enterprise computing and telecoms industries have for many years used the technique of network simulation to test the performance of network devices and systems. Testing in a simulated environment avoids all the drawbacks of drive testing described above:

- with a simulator, the engineer can precisely specify the test conditions, for instance to find out how the DUT behaves when stressed beyond its rated operating limits
- a simulator can exactly reproduce the conditions in which any impairment was discovered, to allow the engineer to analyze whether the failure was random, or was caused by the conditions. The conditions may be precisely and incrementally modified, to allow the engineer to measure the exact operating point that triggers a fault.
- every test parameter may be tightly controlled, enabling the engineer to isolate the cause of

any observed behavior in a complex network environment

- in a simulated environment, every aspect of the network's behavior, including the timing of every packet's transmission and reception, may be precisely measured at every node. In a prototype vehicle network, nodes lack this detailed and accurate analysis and reporting capability.

By carrying out performance testing, automotive manufacturers can find the answers to questions such as:

- will the network be able to handle the peak traffic loads forecast in the application under test?
- in various operating scenarios, does high-priority traffic reach its destination with the specified latency and synchronization?
- if 20% of the network's bandwidth is reserved for high-priority traffic, what happens when the amount of 'best effort' traffic is twice as high as is normally expected?

In fact, the benefit of using network simulation is that it allows the test engineer to devise any kind of 'what if?' scenario, and measure precisely every aspect of the DUT's behavior in it. This network simulation capability also enables negative tests, when the network is deliberately made to work outside its specified operating parameters. For instance, a network simulator can test how synchronized audio/video data streams behave in the temporary absence of the network's master clock.

Test configurations that may be implemented in a network simulator such as the Spirent 16-port BroadR-Reach TestCenter include:

- emulation of multiple talkers or listeners on each port (see Figure 2)
- mixed TSN and non-TSN traffic
- two-armed test set-up, in which the simulator acts as the talkers and listeners, for instance when testing a switch or bridge
- one-armed test set-up, in which the simulator acts as either the talkers or listeners, for instance when testing an end point such as an Ethernet transceiver

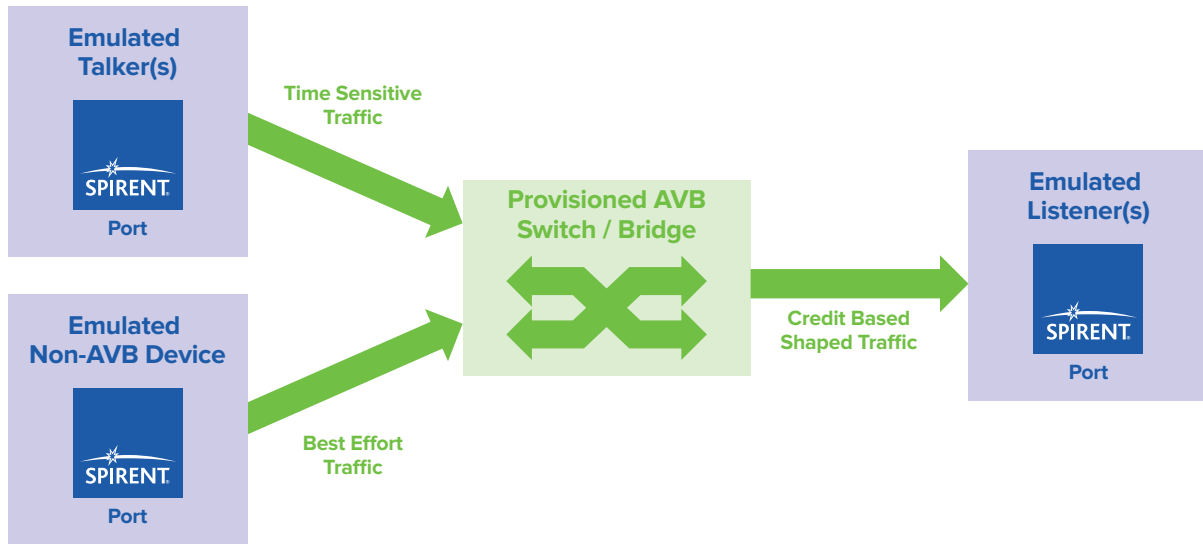


Figure 2: A multi-port simulator may emulate a wide variety of network configurations

The ability to emulate TSN and non-TSN end-points allows the Spirent TestCenter to create a realistic network environment around a device or system under test.

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Examples of test cases used to verify network behavior

Because the configuration of a network simulator is flexible, it may be used to implement an extremely wide variety of test cases. Examples of the types of test cases that manufacturers of Ethernet TSN devices might want to implement include the following.

Lip-synced multimedia playback testing

An Ethernet TSN network may be required to deliver multimedia content, such as a movie played on the car's DVD player or a surround-view image collated from multiple cameras.

Multimedia content requires synchronized delivery to multiple displays, a collated single display, speakers, and headphone ports (see Figure 3). A simulator enables the tester to verify the network's bandwidth reservation, network timing and synchronization, and to precisely measure the timing variance between one output device (such as a display or speaker) and another.

Use-Cases–Lip-synced Multimedia Playback

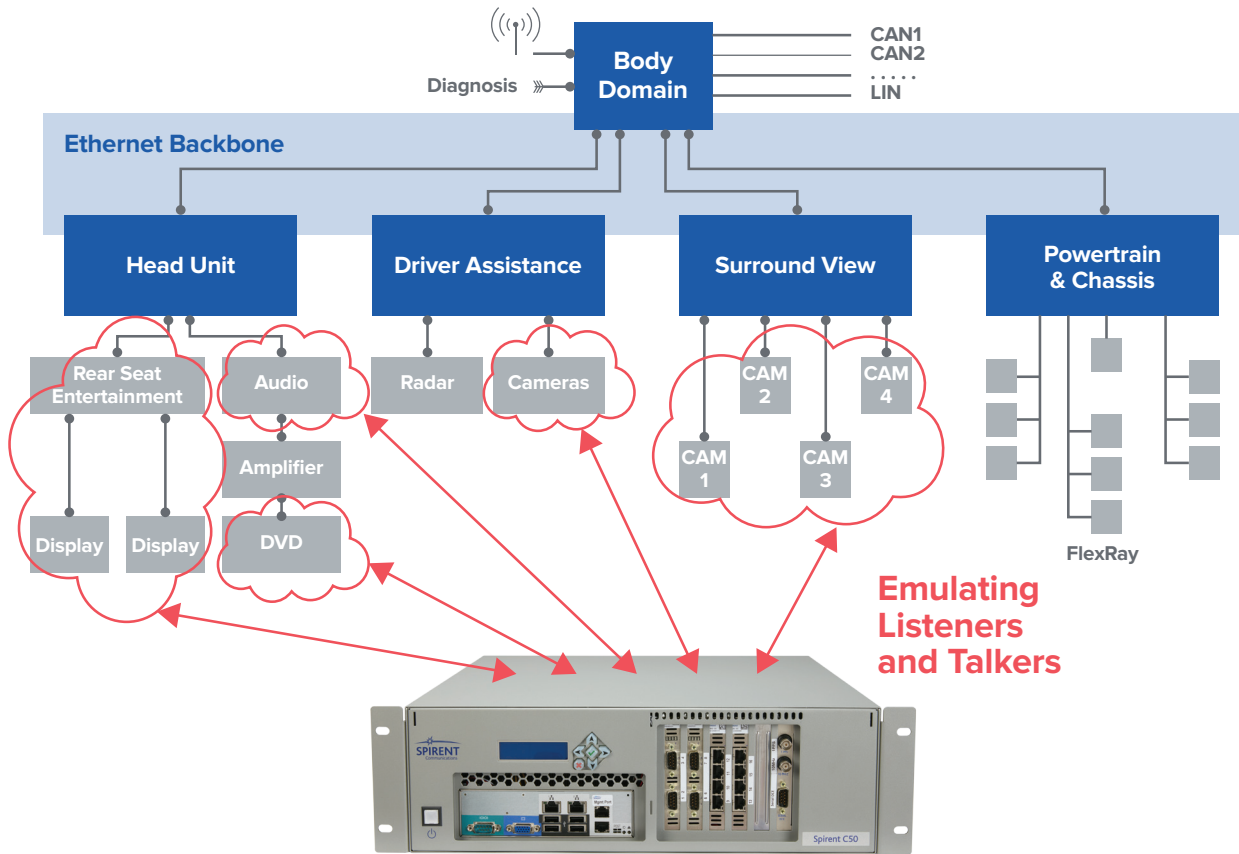


Figure 3: A network simulator can emulate the transmission of streaming audio/video content to multiple end points

Emulating listeners and talkers in ADAS

ADAS equipment in cars enhances the safety of the driver, passengers and other road users, providing enhanced information to the driver and the vehicle about the environment around the vehicle, and taking autonomous actions such as emergency braking for collision avoidance. In safety applications such as collision avoidance, signals from ADAS sensors and signals transmitted to the brakes have to operate with tightly bounded latency. Network simulation allows the test engineer to verify that latency bounds are not exceeded. A simulator provides precise measurement of the times of transmission and reception, and enables simulation of adverse network conditions such as data overload, or multiple simultaneous talkers (see Figure 4).

Use-Cases–Advanced Driver Assistance Systems

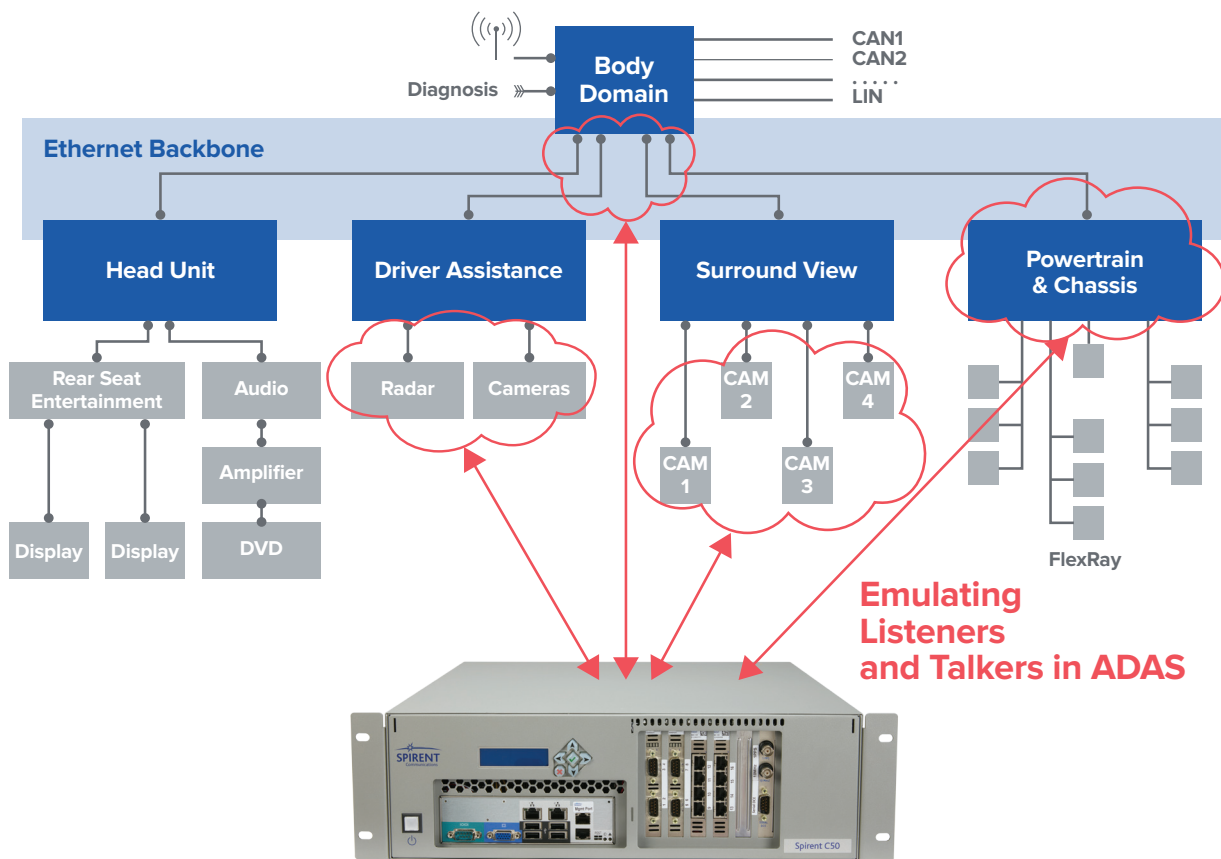


Figure 4: A simulator tests latency in the transmission of safety-critical and time-sensitive ADAS sensor signals

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Testing car-to-X communication (Connected Car)

The car is increasingly operating as an internet end point. For instance, the operation of enhanced navigation systems will in future draw on

real-time road traffic information supplied wirelessly over the internet, and overlaid on the car's mapping application.

Vehicle manufacturers will benefit from using an Ethernet network as the backbone for all the car's communications. An Ethernet network with mixed TSN and non-TSN capability must be able to handle high-priority and best-effort data appropriately.

With a network simulator, the test engineer can discover how the network behaves, for instance, when there is competition for bandwidth between the mapping application, which wants to download traffic information in real time, and the audio/video display application, which has minimum QoS parameters for the seamless delivery of streamed movie content (see Figure 5).

Use-Cases–Connected Car Application Telematics / Car2X

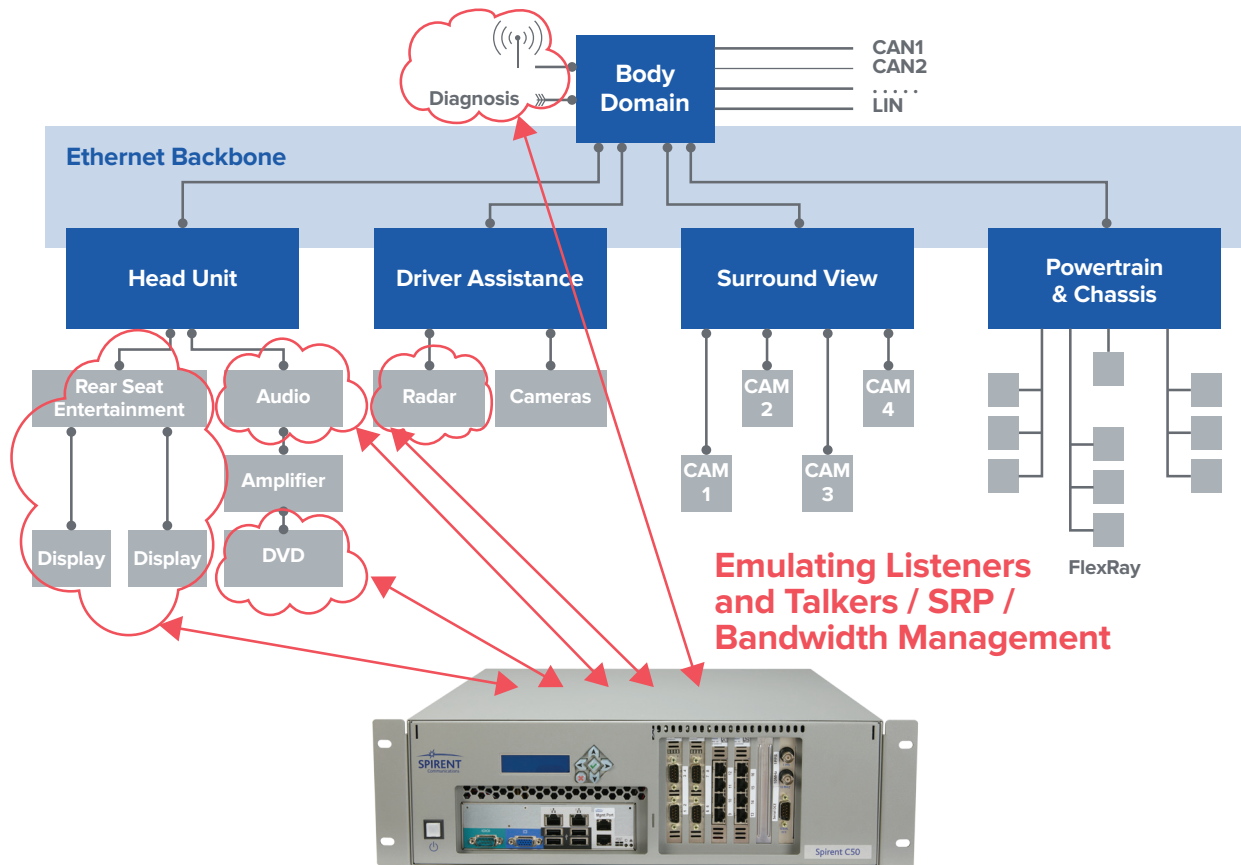


Figure 5: An Ethernet implementation must correctly handle competition for bandwidth when supporting high-priority services that have minimum QoS requirements

Emulating components for connectivity and throughput testing

The integrity of the physical layer of an Ethernet network is essential to its performance. Network simulation enables device and system manufacturers to measure the throughput of connections and wiring harnesses used in their application, and to verify that the connections are sound (see Figure 6).

Use-Cases–Ethernet Connectivity Diagnostics

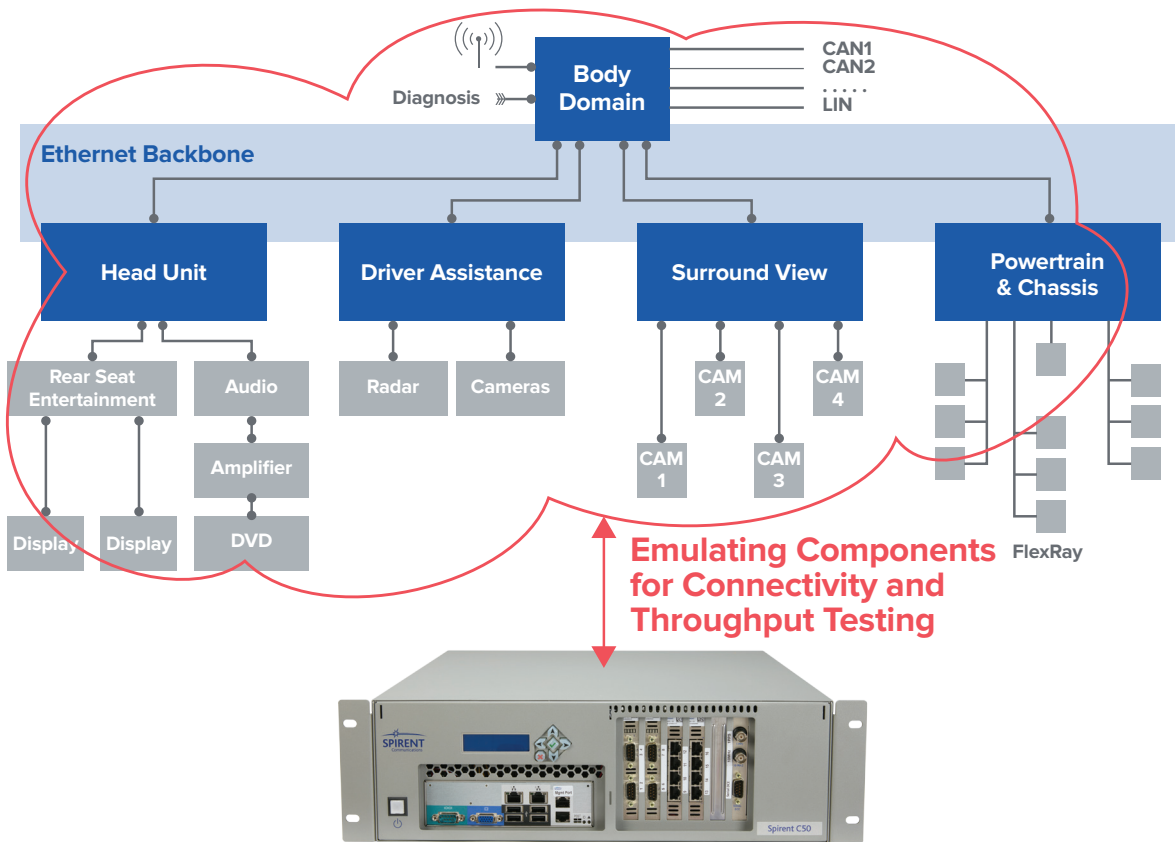


Figure 6: Network infrastructure such as cabling and switches require verification in various operating conditions

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About Spirent Communications

Spirent Communications (LSE: SPT) is a global leader with deep expertise and decades of experience in testing, assurance, analytics and security, serving developers, service providers, and enterprise networks.

We help bring clarity to increasingly complex technological and business challenges.

Spirent's customers have made a promise to their customers to deliver superior performance. Spirent assures that those promises are fulfilled.

For more information, visit: www.spirent.com

How to draw the maximum benefit from network simulation

This paper has described the benefits of conformance testing and network simulation as part of the test and verification strategy implemented by developers and manufacturers of automotive Ethernet networks, network equipment and components.

Used as a complement to other test methods such as drive testing, network simulation in particular can help to dramatically accelerate the product development process. In addition, by providing comprehensive coverage of all relevant test cases in the laboratory, it enables the manufacturer to verify the performance of its product across the entire range of its rated operating conditions. Together with comprehensive conformance testing, this also supports the manufacturer's safety and quality-assurance processes, providing precise measurement of performance impairments and analysis of failure modes.

Most of all, by acquiring test results from network simulation, manufacturers of automotive network equipment and devices can avoid substantial and potentially costly risks. Under extreme stress, for instance, safety-critical network systems might fail to operate within the specified latency bounds, slowing the vehicle's response to a potentially life-threatening situation.

A network simulator allows the test engineer to quickly and easily simulate all potential real-world conditions, no matter how extreme, to verify the limits of the network's performance.

The portfolio of automotive network testers from Spirent is packed with productivity and user-interface features which make it easy for test engineers to design and configure appropriate test routines, while offering extremely accurate and precise measurement of performance parameters such as network timing, packet loss and capacity utilization.

This portfolio includes:

- **Spirent Automotive C1:** an award-winning layers 2-7 test tool supporting a 10/100 BroadR-Reach line rate and Gigabit Ethernet test ports
- **Spirent Automotive C50:** a complete layers 2-7 test tool in a 3U form factor, the C50 offers a perfect blend of realism, scalability and performance
- **TTworkbench AVB Conformance Test Suites:** a comprehensive set of test routines for Ethernet TSN conformance testing
- **Spirent TestCenter AVB Performance Protocol Emulation Package:** a complete implementation of the AVB/TSN protocols, configurable via a graphical user interface and wizards, and providing AVB-specific statistics and measurements for performance and scalability testing.

More information about all of Spirent's test solutions for automotive Ethernet may be found at www.spirent.com/Automotive.



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