Introduction

The automotive industry is preparing to deploy the next phase of the connected car evolution which incorporates a wide range of technologies for various wireless connectivity services. These services can be split into two main categories. The first category deals with the improved safety and traffic management possibilities that car-to-car connectivity and enhanced navigation systems create. The second category addresses the applications that linking the car to the internet via cellular and wireless broadband enable.

In the face of rising wireless system complexity, automotive manufacturers will need to continue to invest in extensive testing to ensure connectivity performance and reliability are maintained over the lifecycle of the vehicle. Development time and cost is likely to increase substantially as a result of this surge in testing. This paper highlights several development challenges that arise from the implementation of complex vehicle wireless systems and discusses how the automotive industry can easily adopt test methodologies used in the mobile industry, where testing is typically conducted in the early stages of the development cycle when issues are less complicated, time-consuming and expensive to rectify. This would enable the automotive manufacturers, Tier 1 suppliers and module manufacturers to significantly reduce the development time and cost associated with delivering their connected car vision.
Increased Car Connectivity Complexity Drives Testing Needs

End-users are likely to increase their expectations of mobile connectivity performance and many analysts suggest that in-vehicle quality of experience will have a significant impact on the connected car market’s development rate. In the case of information services, the quality of experience – in terms of coverage and connection speed – will need to exceed those levels already established in the rapidly evolving consumer mobile market. In the case of safety and traffic flow management, other parameters such as connection reliability and robustness will also prove vital.

From a development perspective, it is quite challenging to deal with an increased level of wireless connectivity complexity while simultaneously improving reliability and robustness. This situation can easily lead to a steep rise in the risk of finding an issue that requires major redesign in the later stages of vehicle development or even when the vehicle is being used. In recent times, several high performance handset platforms from leading manufacturers have suffered from the ‘death grip’ syndrome where simply holding a device in a certain way changes the antenna sensitivity by over 10 dB. Despite rigorous testing and certification, this defect was only detected in the field. The material complexity and operating environment of a vehicle is obviously much greater than that of a mobile device, which means that the scale of the verification problem also increases.

![Graph showing test complexity rising steeply](image)

Figure 1. Test complexity rises as the connectivity mix expands

Typically, automotive manufacturers perform extensive vehicle wireless connectivity testing in the later stages of the development cycle and rely heavily on road drive testing. Manufacturers adopt this approach because predicting or simulating the impact of vehicle structure on radio performance prior to assembly of the prototype has proven difficult and highly unreliable. Due to the sharp rise in test complexity, Tier 1 suppliers and vehicle manufacturers normally conduct most of the wireless related testing when material construction of the prototype is relatively mature. As a consequence, next generation connectivity platforms are expected to have a considerable impact on test time and cost, with some analysts estimating a five to ten fold increase in test cost and time compared to today.

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2. European Commission Connected Car Agenda
Connecting the Vehicle to the Internet

Future applications, including enhanced traffic information services, multimedia services, vehicle relationship management (VRM) services and baseline emergency call capabilities, will rely on the quality and reliability of the vehicle's ability to connect to the wireless network. Although LTE is the preferred radio access technology option for next generation systems, cellular networks will also need to provide backwards compatibility with 2G/3G in order to provide consistent service delivery. The evolution of cellular networks is primarily driven by requirements set by mobile platforms, not the automotive market. This may impact the way some of these future applications are developed and tested.

Because of the huge volume of data that in-vehicle systems are expected to create, vehicle service connectivity is likely to be provided by both the conventional cellular network and Wi-Fi (through LTE/Wi-Fi data offload). This means that in order to deliver the medium term baseline service vision, automotive wireless connectivity solutions embedded into the vehicle will need to support LTE, 3G and 2G, as well as Wi-Fi 802.11 air interfaces. Each air interface needs to be tested separately across the worst-case network conditions that the vehicle is likely to encounter. Additionally, interoperability between each air interface also needs to be tested. Testing modem redundancy is also important for meeting reliability requirements.
Emergency call mandates (eCall and ERA-GLONASS)

At a recent automotive conference\(^1\), a panelist was asked whether or not extensive cellular performance test and network compliance is really necessary and replied in the affirmative by highlighting the importance of rigorously testing features such as emergency call (eCall). European governments have mandated that this feature must be integrated into every new car sold after 2018. Russia has similarly mandated ERA-GLONASS be integrated in every new car to be sold after January 2017. The aim of this initiative is to reduce accident response time to half the current average. To achieve this target, cellular connectivity (2G/3G/LTE etc.) to emergency services must be established immediately and maintained long enough to report the location and scale of an incident that is reported by the driver or automatically triggered, for example, by the release of an airbag.

Intelligent transport systems (V2X)

Vehicle safety solutions – Vehicle to vehicle (V2V) and vehicle to infrastructure (V2I), collectively referred to as V2X – also need to be tested. The drivers behind deploying this technology are clear. In the US alone, over 400,000 accidents occur annually, with a total economic impact estimated at 800 billion US dollars, close to 2% GDP\(^2,3\). V2X connectivity using Dedicated Short Range Communication (DSRC) is based on extensions to the Wi-Fi standard (802.11p). Many countries in Europe, USA, Japan, South Korea, and Australia are running trials to deploy this technology, which means that yet another significant air interface needs to be tested. The U.S. Department of Transportation (DOT) is working towards regulation which will make DSRC for V2V mandatory for all cars very soon.

Ensuring wireless connectivity performance and reliability

Vehicle navigation systems as well as location reporting for emergency call services, rely on satellite communication, specifically GPS (USA), Galileo (EU), GLONASS (Russia) and BeiDou (China). From a wireless test perspective, satellite data reception needs to be tested in isolation and in coexistence with reliable interaction between the cumulative on-board wireless systems listed above. Other vehicle wireless air interfaces that need to be validated include in-car Bluetooth and Wi-Fi radios operating in the ISM band\(^4\).

From an integration perspective, multiple radio transceivers within the vehicle are in very close proximity. This means that the transmit power of one transmitter may be much higher than the received power level of another receiver. In many cases, with intelligent use of contemporary filter technologies and sufficient frequency separation, the transmit signal does not cause significant interference.

However, for some coexistence scenarios such as different radio technologies within the vehicle operating on adjacent frequencies, current state-of-the-art filter technology may not provide sufficient rejection. This problem is further compounded by the fact that final material composition of the vehicle is not known until late in the development cycle and consequently interference modes and paths become increasingly difficult to predict in real-world network connection scenarios. For example, when integrating navigation and cellular wireless systems, automotive manufacturers need to fully test the satellite data reception in isolation as well as in co-existence with active on-board wireless systems under worst case conditions. For collocated LTE and GNSS systems, LTE Band 13 (UL: 777-787 MHz) /14 (UL: 788-798 MHz) can interfere with the L1/E1 frequency of GNSS (1575.42 MHz) as it is close to the second harmonics of band 13/14 (1554-1574 MHz for band 13, 1576-1596 MHz for band 14).

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1. TU Automotive Detroit Conference June 2015
3. TU Automotive panel session, Nevada State Legislator presentation
4. The industrial, scientific and medical (ISM) radio bands are radio bands (portions of the radio spectrum) reserved internationally for the use of radio frequency (RF) energy for industrial, scientific and medical purposes other than telecommunications.
Reducing Late Stage Drive Testing

Although the automotive industry is relatively conservative in nature and reluctant to move away from established best practices, some progressive organizations are evaluating solutions from wireless testing specialists such as Keysight Technologies, Inc. with the aim of making real-world field conditions available much earlier in the development cycle. The mobile device industry, with its a strong focus on performance, low cost and shorter development cycles, uses test methodologies that could be easily adopted by the automotive industry.

Virtual drive testing is an example of a test methodology that has been proven to accelerate product rollouts and quality assurance testing in the mobile industry. Keysight’s Anite Virtual Drive Testing Toolset is a lab-based performance and interoperability test solution that integrates industry-leading lab and field test tools with a sophisticated test automation environment. Virtual drive testing provides the ability to cost effectively verify the end-user quality of experience and significantly reduces field testing through accurately replicating vehicle field drive testing. With Keysight’s Anite Virtual Drive Testing Toolset, automotive manufacturers can capture and record a number of parameters including network settings, signaling to the car module, responses from the car module, radio (RF) environment in and around the car based on the traffic and reflections from other cars, buildings, trees etc. in addition to satellite signals such as GPS, GLONASS, Galileo and BeiDou.

Data captured in the field is used to build tests that replay drive routes in a virtual environment by emulating real-world RF network conditions in the laboratory. This replay can be performed in combination with Keysight’s Anite 9000 network simulator. The Keysight’s Anite Virtual Drive Testing Toolset’s powerful automation capability enables repetitive testing of virtual field test routes for different use case scenarios. This leads to reliable and cost-effective device benchmarking and resolution of issues found in the field during the early stages of product development.

Figure 3. Virtual Drive Testing Toolset uses data captured in the field to build tests that replay routes in a virtual environment by emulating real-world RF network conditions in the laboratory.

1. Measurement uncertainty, channel simulation, and disturbance characterization of an over-the-air multi-probe setup for cars at 5.9 GHz (http://lup.lub.lu.se/record/7760628)
Automotive over-the-air (OTA) performance testing is used to assess the user’s experience when accessing vehicle onboard data services by replicating real-world conditions as seen by the vehicle antenna cluster. When a radio wave interacts with an object, the wave is scattered, diffracted, reflected or absorbed. Radio channel emulation aims to accurately replicate this behavior. Recreated RF network conditions include: multipath propagation, Doppler Effect, angles of departure (AOD), angles of arrival (AOA), and noise/interference, as well as all of the typical channel conditions between the base station or access point and the vehicle antenna cluster.

Automotive OTA testing uses channel emulators in an anechoic chamber (non-reflective) to accurately emulate different radio environments such as urban, suburban, rural, and indoor areas. Recently, the mobile device industry (via CTIA) has standardized MIMO OTA testing in order to accurately assess the performance of a device. This testing methodology can be effectively used in vehicle wireless connectivity development.

Keysight has contributed substantial channel emulation expertise to the CTIA MIMO OTA subgroup (MOSG), which has been investigating MIMO OTA performance since March 2011. The subgroup has recently agreed (with support from all CTIA operators), to move forward with two different types of OTA activities, and both recommendations have been adopted by leading independent test houses in China, Taiwan, Europe and US who are deploying anechoic MIMO OTA test laboratories.

Keysight works with Tier 1 mobile operators worldwide to develop acceptance test cases that device manufacturers use to ensure their products perform as expected when launched. Major modem chipset, reference design and wireless product manufacturers run these scripts in SAS (Keysight’s interoperability and performance test solution, which uses the Keysight’s Anite 9000 network simulator) during product development and conformance test cycles.

Such capability supports automotive system development, as it enables the data throughput performance of in-vehicle software and hardware modules to be tested against mobile operator requirements from multiple geographic regions under real-world network conditions prior to final integration into the vehicle. This strategy has the potential to drastically reduce the amount of performance related test needed by highlighting system issues that impact quality of experience much earlier in the vehicle development cycle.
Conclusion

Discussions in technical forums, automotive industry journals, and conferences as well as feedback from vehicle manufacturers all confirm that the automotive industry clearly understands wireless test complexity and associated issues. There is however a prevalent view that meaningful wireless connectivity testing is not realistic prior to integration of the Telematics Control Unit and the antenna cluster in a mature vehicle prototype. Experience from the mobile wireless industry strongly suggests otherwise: test strategies based around the Keysight’s Anite Virtual Drive Testing Toolset, Keysight’s Anite 9000 network simulator and the Propsim channel emulator, enable early stage wireless connectivity and system performance tests in the laboratory that can easily be replicated and fine-tuned later in the vehicle prototype as well as in the field. By adopting these test methodologies, automotive manufacturers can significantly reduce costs and time in the development phase.