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Fourth Generation Wireless - Vehicle and Highway Gateways to the Cloud

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16. Abstract

This paper examines next generation wide-area cellular such as fourth generation (4G) will be able to support vehicular applications, and how transportation infrastructure may mesh with wireless networks.

This report is part of the *Connected Vehicle Technology Scan and Assessment* project. This two year scanning series of *Connected Vehicle Insight* reports will assess emerging, converging and enabling technologies outside the domain of mainstream transportation research. ITS America seeks technologies that will potentially impact state-of-the-art or state-of-the-practice in ITS deployment over the next decade, with an emphasis on the "connected vehicle."

The *Technology Scan Series* notes trends, technologies, and innovations that could influence, or be leveraged as part of, next-generation intelligent transportation systems within the next five to seven years. The series' focus is on developments in applied science and engineering and innovation in data acquisition, dissemination, processing, and management technologies and techniques that can potentially support transportation.

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Introduction

With Fourth Generation cellular (4G), we will see the complete extension of the internet suite of protocols to the wireless environment. 4G likely represents the end of the traditional siloed telecommunications approach that has been the result of decades of investment in single-application "purpose built" wireless technologies (e.g. radio, TV, land mobile, and cellular) and regulatory practice. Current investment patterns in infrastructure provide a strong indication of what will be available and provided in what quantities, quality, and cost beyond 2015 for both terminal devices and network infrastructure.

This paper examines how next generation wide-area cellular such as 4G will be able to support vehicular applications, and how transportation infrastructure may mesh with wireless networks. Specifically, it suggests that automotive electronics engineers will need to be cognizant of how application data is treated by 4G Long Term Evolution (LTE) networks, and how innovations such as self-organizing femto-cells, "traffic shaping" and heterogeneous or "vertical roaming" across different radio access technologies may improve the performance of off-board or "cloud" -based vehicular applications.

Furthermore, the paper suggests that over the long term, vehicles will serve as wireless gateways that manage and collect data a number of devices or sensors deployed in vehicles and highway infrastructure, utilizing 4G cellular as the last-mile wide-area connection to the cloud. 4G will likely manage devices and sensors that utilize a variety of short range radio access technologies such as Wi-Fi that provide the "last yard" connection.

Lastly, peer-to-peer short range communications systems will expand. Peer-to-peer systems seek opportunities to communicate directly to other nearby nodes without the need to sluggishly route data traffic to and from cell towers first. Peer-to-Peer technologies include ZigBee, Bluetooth, WiFi-Direct, and FastLinq, and will likely connect consumer devices to vehicle consoles to support a number of telematics applications from mobile devices. Lastly, vehicles will also likely have peer-to-peer wireless systems devoted to safety-critical or highly mobile "spot" communications, based on Dedicates Short Range Communications/Wireless Access for Vehicle Environments (DSRC/WAVE). DSRC/WAVE will support high speed, high integrity local applications such as vehicle-to-vehicle cooperative collision avoidance, or vehicle/infrastructure applications, such as tolling or traffic signal preemption and intersection collision avoidance.

Fourth Generation wireless will provide a core gateway to manage a number of systems that will be found in transportation. 4G gateways may be conduits to securely configure and administer peer-to-peer communications systems and other last-yard personal devices or machine-to-machine sensors, as is being contemplated in other industry sectors, such as tele-health, smart energy, and home and industrial automation. Vehicles will likely leverage these personal and machine devices for the computing resources and sensors installed in them, taking advantage of the devices' ability to add the latest generation of technology without expensive retrofitting. In transportation, these gateways systems and devices will, however, need to be infused with an intelligence that manages personal device interaction with the driver to ensure that they do not represent a distraction to the proper operation of the vehicle. Furthermore, these vehicle gateways , will likely increasingly manage service connections across different wireless access points embedded in transportation infrastructure, such as

DSRC/WAVE or Wi-Fi nodes, or even small 4G femto cells that that may be increasingly set up along road corridors.[1]

Smarter, Denser 4G Networks: the Intersection with Highway Infrastructure

The wireline internet was never designed to support mobility and wireless services, where transport protocols function poorly because wireless links frequently fail, forcing retransmissions, and devices constantly change home addresses as they geographically "roam" across wireless subnets. 4G radio access and core networks are designed to manage these challenges, and will likely improve wireless network performance – specifically higher quality of service, reduced latency, improved reliability, and enhanced capacity.

4G is a not just an industry quest for a faster radio technology. It is a remake of the entire cellular telecommunications system with the objective of extending the internet suite of protocols beyond the wired environment. 4G represents the complete transition of cellular from a system designed for the unique requirements of voice to a general-purpose system that can manage a number of applications. In 1983, for example, mobile subscribers experienced voice throughput of about 10 kilobits per second (kbps). A decade ago, end-users could expect peak throughput of approximately 170 kbps with Second Generation (2G) technologies. 4G technologies are designed to meet, or at least approach, the International Telecommunications Union (ITU) requirement that targets peak data rates of up to approximately 100 Mbps for high mobility access (e.g. outdoor access, with users moving at high speeds) and up to approximately 1 Gbps for low mobility or "nomadic" access (i.e. primarily indoor access, with terminal movement at a minimum). [2]

However, traffic is expected to explode on cellular networks and all Mobile Network Operators (MNOs) are committing to aggressive deployment of 4G technologies, with new terminals (handsets, USB dongles, laptops) already becoming available as soon as infrastructure is deployed. Conversion to 4G would mean re-farming 2G spectrum by decommissioning 2G base stations that support current M2M (Machine-to-Machine) and vehicle telematics services and converting them to either Third Generation (3G) or 4G wireless technologies.[3]

Although the number of wireless data subscribers grew significantly in the last several years, traffic per subscriber has increased several orders of magnitude more. In the face of such traffic growth, a fixed line Internet Service Provider (ISP) would, for example, simply add additional link capacity, a strategy unavailable to an MNO that cannot provision beyond its fixed allocation of spectrum. Lack of new spectrum is a major constraint on MNOs. It is understood that we may be within a factor of ten of the maximum capacity that can be achieved within a given spectrum allocation, and that there are few options to increase capacity beyond more spectrum and aggressive cell splitting or spectrum re-use.[4] One of the keys to cellular's future success, however, is the architecture's ability to "create" spectrum through the re-use of wireless channels over large geographical areas, and the latest trend is to expand capacity by splitting cells into smaller and smaller units. This shrinking of cell sizes has been a consistent technology trend over several decades. For example, the first mobile telephone systems of the late 1970s had "macro" cells of nearly 700 square miles each, but current small (micro-, pico- and femto-) cells range from a half square mile to 50 square feet. The definition of small cells varies. Femtocells describe cells with a range of 10 meters, with picocells 200 meters or less, and microcells nearly two kilometers.[5] Future mobile wireless networks will include combinations of macro cells and many smaller scale femto-cells.

The number of wireless nodes with which a vehicle may potentially establish communications will likely multiply in the next decade. There will be likely be a massive build-out of new wireless infrastructure, both cellular but also short-range "local area" systems such as WiFi, DSRC/WAVE, and others. The reason for the build out is simple and part of a century-long trend. Assuming no radical breakthroughs occur in radio technology, the only way to create more network capacity is by splitting cells, re-using spectrum, multiplying access points and allocating them to ever smaller coverage footprints.[6] Accommodating the growing traffic that millions of mobile and machine sensor devices will generate in the future requires a completely new infrastructure provisioning strategy for MNOs, a strategy that possibly represents an accelerating trend toward much higher wireless access point density and accessibility.

By creating and deploying faster radio access technologies, such as 4G LTE or WiMAX, and deploying more cells, MNOs provide more capacity and speed in the wireless channel for users, but this tends to move congestion upward into the backhaul networks that connect radio access networks to the core network and the rest of the internet. Expanding backhaul from cells is a high priority for MNOs, and the cost of backhaul influences whether splitting cells is cost effective. Whether smaller cells and cell splitting are a cost-effective strategy is hotly debated in wireless industry circles, as the marginal benefit/cost of cell splitting depends on the availability of cheap wireline backhaul (such as customer's cable internet) and the cost of alternatives such as the siting and construction of more "macro" cell towers. Femto cells will likely be built off the existing telecommunications plant supporting wireline broadband, and leveraging this backhaul will be critical for cost-effectiveness and growth of femtos.

New femto-cell infrastructure deployment is a potential MNO strategy to dislodge two capacity bottlenecks at once -- spectrum and backhaul from the radio access network to the public internet. The spectrum bottleneck is being resolved by cell splitting into femtos, and the wireless backhaul problem is being overcome by taking advantage of existing home and business wireline internet access to connect these new mini- base stations. In the future, mobile phone or cable customers may not only purchase a phone with their data plan, but may also get a home femtocell base-station that can be connected to their broadband cable internet at home to provide improved coverage indoors, but also to relieve congestion on MNOs' macro base-stations. The cost of these systems is dropping -- the first sub-$100 femto-cells can handle eight simultaneous calls and download speeds of up to 14.4Mbps.[7]

Femtocells have not taken off as wireless industry analysts have expected, as MNOs have focused more on installing and expanding macro base station infrastructure. However, despite the less than expected growth, Informa Telecoms & Media recently estimated that worldwide femtocells now outnumber macro-base stations, with 2.3 million 3G femtos deployed compared to 1.6 million 3G macrocells.[8] Furthermore, femtocells are also adding air interfaces to support multiple standards. Ubiquisys, Texas Instruments, and Intel are working on femtocells that support Wi-Fi, 3G, and 4G LTE.[9]

To meet consumer and enterprise demand for wireless data services, the density of wireless network infrastructure has expanded enormously over the last decade, and will continue to expand. In 2000, there were nearly 80,000 macro cellular base stations in the US, growing 210% to approximately

250,000 macro cellular base stations currently. If wireless carriers commit to seriously provisioning smaller cellular base stations such as femto-cells, conservative estimates indicate that telecom operators may add 50,000 additional base stations a year to their networks between 2010 and 2015. Highly optimistic estimates indicate that wireless carriers' networks nodes might incorporate many more micro base stations, with nearly six femto cells being implemented for every macro cellular tower.

The efficient and economical deployment of thousands or even millions of small cells necessitates a drastic change in management and radio planning methodologies. Traditional macro networks are deployed with a semi-static configuration whereby cell planning to reduce inter-cell interference is done via simulation and spectral analysis. This approach is not feasible when the cell size is reduced and the number of cells increases drastically. The development of Self Organizing Network (SON) techniques, algorithms, and eventually standards is a critical step in femtocell deployments.

Current femtocell techniques rely on algorithms that are self-contained within each base station, lacking coordination among cells and focusing primarily on power control to reduce inter-cell interference. The next generation of SON will extend these algorithms to include coordination among cells as well as to take into account power control and parameters like cell loading and proximity of terminals to the radio. Organizations such as the Third Generation Partnership Project (3GPP) have already identified SON as a critical area for standardization and work is already underway. SON will likely appear in later versions of LTE Advanced specifications.

Ultimately, femtocells are seen as not only boosting the capacity of the macro cell network by offloading indoor users, but as driving technical innovation in SON base stations, cells that automatically manage and mimimize inter-cell interference. Such innovation will likely drive further standardization of base station interfaces, so that someday MNO's can mix different base stations instead of purchasing from a single supplier, which expand competition, and through increasing economies of scale and scope, push costs down further.

Indoor femtocells are simple and more affordable than outdoor, given that indoor femtocells can utilize existing power and wireline broadband backhaul found in most homes and commercial buildings. Outdoor femtocells, one that might be found mounted on the outside of buildings, utility poles, lamp posts, traffic lights or other roadside fixtures are more costly to deploy for a number of reasons. Zoning, access to right-of-way, power, and the requirements to harden and secure equipment that must operate reliably in all weather conditions all add to the cost. Futhermore, outdoor femtocells may not be able to leverage the existing telecommunications plant for backhaul that exists for indoor systems, which is the greatest cost. (As percentage of capital expenditure for build out of a typical macrocell, backhaul is nearly 50%). In order to keep backhaul costs down, outdoor femtocells will likely rely on wireless backhaul, such as microwave, which can still be cost prohibitive and in some instances impractical, as microwave relies on line-of-sight transmission, which is difficult to configure in built-up urban areas. Nonetheless, by 2016, an estimated 58% of outdoor small cells will be backhauled using wireless techniques, according to ABI. There has not been any significant outdoor small cell deployment yet, as operators are still in the process of trialing and testing small cell backhaul technologies.[10]

The practicality of outdoor femtocells depends on falling costs for network management and wireless backhaul, on a per basis cell. Beside the development of Self Organizing Network (SON) technology, future success of outdoor femtocells may depend on much lower cost wireless backhaul. One promising technology in reducing cost of backhaul is “whitespace” systems. Whitespace systems have coverage areas far greater than a macro cells and are designed to find gaps in spectrum over time, frequency and geographical space, and may be ideal for predictable last-mile traffic backhaul. Whitespace systems are a potential wildcard, one that if technology and regulatory models work out, may present a potential boost to outdoor femtocell systems.

Whitespace systems are “cognitive” radios use intelligence and radio access techniques to avoid interference with incumbent licensees. Whitespace systems find geographic regions and times where allocated spectrum is unused by the licensee --for example, North American TV bands in the 54-862 MHz band have been observed to remain largely on the unoccupied in many regions. Also known as Wireless Regional Area Network (WRAN), whitespace system’s architecture is similar to WIMAX and as defined as by IEEE 802.22, and is being designed ensure co-existence and coordination with incumbent TV licensees and other WRAN operators to avoid interference and ensure quality of service.

Regulatory, business, and pricing models between incumbents spectrum licensees and WRAN providers must also be developed, along with technology development, before whitespace can be made available in the commercial marketplace. It is hotly debated whether whitespaces should be used for backhaul to femtocells and other local area wireless access points for last-mile connectivity, or should be utilized to provide direct broadband access to 4G mobile handsets. However, if licensing issues are resolved and commercial whitespace systems emerge, cost of backhaul may fall drastically for femtos.

Ultimately if deployment of outdoor femtocells finally does take off, vehicles equipped with telematics systems will likely be connecting to them as they are parked, or move in and out of smaller coverage areas such as home driveways, parking garages, or even intersections and other confined spaces. Furthermore, outdoor femtocells could even support some non-safety critical point-of-presence “spot” applications in the distant future, such as cordon or road tolling, road or parking access and control, and even parking spot usage recognition in areas where cellular coverage may be problematic. However, for these applications to work, MNOs will need to acquire highway right-of-way and other easements to allow buildout of small wireless nodes.

Access to such transportation rights-of-way, such as roads, highway intersections and railbeds, may also be important for the expansion of outdoor femtocell infrastructure. Access to public rights of way, tower sites, and buildings is governed by federal, state and local requirements, depending on the location. For the purposes of federally funded highways, FHWA has adopted the position that wireless providers are private utilities (with facilities that are devoted exclusively to private use) and, therefore, are subject to Section 704 of the Telecommunications Act of 1996.[11] Consequently, wireless providers may be regulated according to Federal statues regulating Federal Aid Highways under the “air- space” provisions, unless state statute defines wireless communications provider as a “public utility.”[12]

In 2011, the FCC issued a Notice of Inquiry to determine whether there is a need for coordinated national action to improve rights of way and wireless facilities siting policies, and, if so, what role the Commission should play in conjunction with other stakeholders.[13] Although they have not yet created a complete record of how rights of way and wireless facilities siting decisions influence the build out and adoption of broadband, the FCC intends to determine whether statutes or ordinances regulating access to public rights of way for wireless facilities have been updated to reflect changes in technology. In particular, the FCC called out the development of micro, pico, femto-cells and distributed antenna systems.

Fourth Generation Networks and Treatment of Vehicular Applciations

Despite the ongoing expansion of wireless infrastructure capacity through upgrades to 4G and continued cell splitting with the introduction of femtocells, latent demand will still likely leave MNOs' networks capacity-constrained in the near future. MNOs will need to manage wireless traffic proactively to ensure that application performance does not suffer. There is one major approach to managing the deluge of data – *traffic shaping*. This strategy relies on the concept of identifying application needs and prioritizing transmissions, or even prohibiting or re-routing transmission to other networks based on MNO operational and pricing policies. The key question is what the impact might be on future automotive connected vehicle applications, specifically how data transmitted from vehicles might be treated by future 4G "traffic shaped" networks.

MNOs recognize that revenue growth hinges upon their ability to deliver a wider range of mobile broadband applications and services, which require higher bandwidth and lower latency. The critical challenge for MNOs is to develop networks where high volume applications, such as video streaming, do not interfere with lower-volume critical applications, such as 911 calls or Automated Crash Notification messages. As cellular systems morph into a general purpose internet-based wireless network, they will be challenged to meet the needs of all applications with the single, "best effort" quality of service class that is typical of the wired Internet. 4G describes and combines several Quality of Service (QoS) attributes, such as maximum acceptable delay or jitter and bit error rate, into a minimum of four QoS categories, including Conversational (e.g. Voice-over-IP), Streaming (e.g. video), Interactive (e.g. web browsing) and Background (e.g. asynchronous file transfer and email).

But future quality of service implementations may need to be more sophisticated in prioritizing content for wireless networks than they would for a strictly wireline network as multiple real-time streams might look alike, but still need to be further differentiated. A video stream can be delayed and cached on the terminal, but a 911 call or an Automated Collision Notification cannot be, for example. However, today's mobile networks are carrying many complex combinations of traffic that potentially defy simple classification of data packets into four broad quality-of-service buckets. Using Deep Packet Inspection (DPI), MNOs may be able to automatically sort and classify packets according to a variety of criteria in real time. After classification, different traffic shaping policies may be applied to the packet and its associated stream such as prioritization, rate limits, or even blocking. Today's DPI systems can identify many protocols and traffic types while shaping traffic in real-time, at speeds of nearly 100 gigabytes per second. DPI, however, may not always be able to distinguish all application traffic, as Internet applications are becoming more sophisticated and application developers are burying data deep inside packets, such as voice and other media mash-ups, significantly increasing traffic classification complexity.

Quality of service was not adopted in the early days of the wireline internet because there was little need for it as most traffic was asynchronous file transfer, email and web browsing, and wireline operators could over-provision link capacity, adding additional optic fiber for example, as a way to combat congestion caused by peak internet traffic. The overabundance of wireline link capacity has allowed the wireline internet to move beyond bulk to asynchronous applications and allowed for the introduction of real-time applications such as unicast video and audio streaming and voice-over-IP (VoIP). [14] Unfortunately, MNOs cannot add spectrum to the wireline telecommunications providers and must be careful of particular applications or users that may potentially act as "bandwidth" hogs.

The dilemma for MNO's is that LTE's all-IP architecture will create a more open environment for application developers, but more applications may greatly increase congestion on networks. So called "Over-The-Top" (OTT) applications, such as real-time Voice-over-IP services like Skype, or video streaming services such as Netflix, in particular are threatening to network capacity. (OTT applications require high bandwith capacity be reserved to support real-time communications.) To overcome this threat, MNO's will need to partner with content and application providers, develop application service store-fronts featuring application programming interfaces (APIs) that expose LTE's value-added traffic-shaping network capabilities to third-party application and content developers for a fee. It is estimated that by 2015, over 70% of mobile network traffic will be real-time streams, such as voice calls or video. As a result, most mobile operators, according to a recent survey, are planning to implement at least four or more levels of QoS.[15] Traffic shaping technology will allow MNOs to introduce flexible tiered quality of service and pricing incentives that fit particular applications. 4G core networks and even terminals will likely have embedded operational policies to differentiate and prioritize traffic and then schedule it for transmission based on time sensitivity or quality of service requirements. Differentiating traffic can also be used to charge different tariffs for different services or by bulk data limits, or charged based on peak or off-peak usage, or to exclude certain types of usage completely under more affordable data plans. This effort is dependent in part on long-term efforts by standards organizations such as 3GPP to create an *IP Multimedia System* as a part of later releases of LTE that will shape traffic on radio access network for transfer to and from the fixed internet.

Designers of automotive applications need to be cognizant of the effect that network congestion might have on their applications in the future. The design of the Internet precludes a state where latency is ever sufficient for all applications at all times, unless the multiplicity of applications is reduced.[16] The wireline Internet and its wireless extension are both dynamic shared bandwidth systems that rely on statistics to gauge quality of service for most applications, and much analysis is needed to understand the impact of different applications to network capacity. For automotive applications where data is processed "in the cloud," such as off-board navigation, an understanding of the application's demands on the network may be important. Even though the *LTE IP Multimedia System* will be able to allow applications the same quality of service as voice calls, application programmers need to have quite detailed knowledge of the network's traffic dynamics to avoid creating congestion or other pathological effects on application performance.

If even after network traffic shaping, MNOs still cannot cost effectively meet the growing traffic on their networks, then one alternative will be for MNOs to "shape" the terminal devices, requiring them to "offload" some traffic to less congested links, such as Wi-Fi networks or even roam to less-congested competitor networks. The emergence of multi-standard, multimode radios such as those found in app phones means that applications will have a choice of interfaces beyond cellular, and these systems may incentivize development of vertical "roaming" across heterogeneous networks, such as Wi-Fi, ZigBee, DSRC/WAVE, or other systems. Models where lower priority traffic (or lower profit margin traffic, depending on the pricing model) is "off-loaded" to these redundant links will take advantage of the LTE *IP Multimedia Systems* capability to implement traffic shaping in both the network and the terminal.[17] Future versions of LTE *System Architecture Evolution* (SAE) include an "anchor" for roaming between 3G/4G systems and Wireless Local Area systems such as WiFi or perhaps eventually DSRC/WAVE.[18] The concept would allow an MNO to establish interfaces to WiFi or

DSRC/WAVE hotspots, maintaining a contact list of trusted nodes that LTE would use to off-load data traffic in the event the normal 4G network is congested.

LTE's future *IP Multimedia System* represents a different approach to the more traditional telecommunications architecture of a set of specific network elements implemented as a single telco-controlled infrastructure. Services will be created and delivered by a wide range of highly distributed systems (real-time and non-real-time, possibly owned by different parties) cooperating with each other as part of the LTE IP Multimedia System. These value added services will be built not necessarily by the MNO's, but by third-party telecommunications service and equipment suppliers and bundled into the IP Multimedia system, provided to application and content providers for a fee, of which the MNO takes a percentage. There will, however, likely be some tension between opening up the IP Multimedia System for third party development and keeping the architecture simple and easy to understand for application service providers, efficient to operate for the MNO's

Since 3G, MNOs have sought "flatter networks" with fewer jumps between the radio access network (e.g. cell tower to mobile terminal) and the core network (cell tower to the internet gateway) because generally the more hops on a network, the more likely you are to encounter bottleneck failures and congestion. For example, LTE currently supports Radio Access Network round-trip times of less than 10 milliseconds, but this does not measure latency as data hops to core wireline gateways, , to transit the internet or other peered networks (Reducing latency in internet transit relies on a number of techniques not discussed here, such as caching content at strategic points closer to the edge of the internet, server load-balancing or some QoS and routing techniques). Flatter networks are also cheaper to build and maintain and are critical in keeping MNO's operating cost-per-bit low, which is critical if tariffs are decoupled from usage (i.e. all-you-can-download, flat rate pricing), as is occurring with many wireless data plans. Again, there may be a conflict between keeping the wirless teleco infrastructure flat and simple to drive down MNO operating costs and adding complexity via more accommodating application-aware interfaces supported in the LTE Multimedia System.

Future 4G systems are being designed to meet the requirements of a wide variety of quality-of-service categories, but application developers will likely still need to experiment with future LTE *IP Multimedia System* features to ensure adequate standardization, as well as performance and priority for applications. Vendors of mobile terminals, network base stations, backhaul equipment, core gateway equipment and systems are typically at different levels of compliance with 3GPP standards, which may make QoS difficult to implement in the short term across all parts of the network. However, MNOs are uncertain what the impact of M2M and Vehicle telematics will be on demand for their network services. In an environment where M2M applications are growing and "human" subscribers are a minority, network communications traffic will likely be bursty, based on either timely automated routines or events that may be unpredictable.[19] Predicting the maximum capacity and provisioning networks to support that M2M peak capacity may be a future challenge in maintaining QoS.

MNO's will need to work with the largest M2M application service providers to understand the implication of M2M on traffic patterns and capacity. MNOs and application service developers may need to be cognizant that traffic shaping and simple QoS classification and prioritization may not always work, or work in ways not intended by application developers.[20] On future wireless networks, application developers must conduct extensive analysis to determine how an application's performance influences, or is influenced by, the variable conditions on the wireless network, and how it may interact with elements with a future LTE *IP Multimedia System*.[21]

This is especially the case for mission-critical systems, but also for ones where there is a high expectation of reliability from the user. "End-to-end" performance management tools are used by network engineers to monitor the symptomatic impact of applications on end-user and service-level performance metrics, but most network management tools only understand the network in discrete, device-level pieces.[22] Consumers may have higher expectations of the quality and dependability of automotive OEM equipment, in contrast to shorter-lived, less durable consumer electronics devices, and automotive application developers may need to invest more time and effort to understand how they can build "end-to-end" quality and reliability into their services that rely on frequent off-board communications.

Vehicle as a Wireless Device Gateway - the Changing Automotive Service Supply Chain

The ITU originally contended that only LTE Advanced and WiMAX Release 2 (802.16m), two emerging technologies, qualify as 4G because they will be able to achieve peak data rates of 1 Gbps for a stationary user. Current systems being deployed are marketed as 4G, such as LTE or WiMax, but do not meet this threshold. The ITU subsequently changed its definition to say that any technology offering a "meaningful improvement" over 3G can be classified as 4G.

Whatever the definition of 3G or 4G, the success of these systems is not because they solved the problem of insufficient data rates. They have been successful because their deployment coincided with mobile terminals such as app-phones and other computing platforms such as tablets that provided portability, ease of use, and application flexibility and upgradability. 3G marked the point in time when the wireless telecommunications industry abandoned the "walled garden" approach of providing a fixed menu of applications proprietary to their networks, abandoning competition at the application layer and leaving it to the information technology (software) and consumer electronics (hardware) industry. These hardware and software platforms, or "ecosystems", parallel wireline internet, such as application/content/service development and distribution models using open application programming interfaces (APIs) and online distribution and maintenance.

In vehicle telematics, there is a potential movement underfoot to move away, at least partially, from the traditional embedded vertical solutions (one telematics service providing all applications) to standardization, through application programing interfaces, middleware and common hardware, that allow horizontal integration of different vendor components and specialized application services. This means that an automotive application developer, instead of having to build from the ground up or purchase exclusive access to large portions of the service supply service chain, can focus efforts on innovations at the application layer.

Over the last decade and a half, automotive telematics and infotainment hardware has evolved from dedicated hardware components, to bus-connected distributed architecture systems, to integrated navigation-centric systems. The last phase are new user-defined systems, such as Ford Sync or newer versions of OnStar that have sprouted interfaces with mobile devices (for hands free voice telephony or voice-to-SMS texting) and are contemplating the creation of app stores that can be used to vet, market, and distribute applications to consumers in the same way as applications are currently distributed by companies like Google, Apple, and RIM for their mobile phone devices.

User defined systems represent a major break from previous strategies where capabilities were defined by the automakers with little input from suppliers or third parties, outside of their supply chain.[23] The fixed menu of applications that had been the stamp of telematics packages in the past will change. Like app phones that allow users to choose *à la carte* from multiple applications, "app stores" create a platform that allows users to choose the mobility applications they want, making the value proposition for telematics more attractive in the eyes of consumers, especially when weighted against the additional cost of supporting the connectivity elements of these systems.

Not only are telematics service providers potentially abandoning the "walled garden," they are also contemplating integration of third party software and hardware solutions found in mobile devices into the vehicle telematics system. Mobile device software integration solutions include mobile devices that act as an application server to the vehicle. For example, Nokia "terminal mode" allows the application, such as a personal GPS navigator, to run on a 3G/4G mobile device, but with the display and user interface translated to a larger screen on the vehicle center stack consul, ostensibly with safer user controls to reduce the risk of driver distraction.[24] Third party mobile device hardware integration solutions are also appearing, blurring distinction between consumer devices, embedded and aftermarket device categories. Garmin, a traditional consumer electronics manufacturer focused on consumer personal navigation devices is breaking into the automotive supply chain. The company recently introduced a portable navigation system that plugs into the vehicle center stack console of the 2012 Suzuki Grand Vitara and SX4 and can also detach for the driver to use on when on foot. TomTom has a similar semi-integrated solution for the Fiat 500 and the Mazda CX-5, and provides a driver interface to some of the vehicle infotainment functions.

Much of the activation, configuration and management of mounted or wirelessly tethered devices in a vehicle need to be done with minimal driver intervention, if not for convenience, but also for the sake of safety and security of the vehicle and the driver. Gateways devices and software, such as terminal mode, will provide direct and unaided interaction between a device management server and the gateway management client. If connected mobile devices merge with the vehicle the most critical issue that must be addressed is the risk that the driver will be overwhelmed by the multiple devices and driver-machine interfaces while they are operating the vehicle.

There is, however, a major risk in mixing automotive and consumer electronics systems in vehicle. The most important problem is ensuring that devices do not distract drivers while they are operating vehicles. Automaker-integrated features are designed for use in the driving environment and the auto industry has established guidelines for driver vehicle interfaces through the Alliance of Automobile Manufacturer (AAM), however, no such industry wide guidelines or best practices exist for electronic devices brought into the car. NHTSA's data shows that almost 5,870 people died and an approximately 500,000 people were injured in crashes that were reported to have involved distraction in 2008. NHTSA plans to analyze the results from the Strategic Highway Research Program 2 (SHRP2) large scale naturalistic driving study to better understand the incidence of device use and corresponding crash risk, as well as identify countermeasures, such as standards to lockout distracting device operation, and laws restricting driver use of distracting devices.

Such research efforts by government, industry and academia are sorely needed. Tablet computers, for example such as Apple's iPad or Blackberry's Playbook, like Personal Navigation Devices may ultimately be mounted in the vehicle console center stack to provide an platform to support applications such as navigation and other mobility services for the driver. New research and better understanding of risks and potential countermeasures of distracted driving may improve design standards of these mobile devices over time. For example, new devices that can be mounted in the console center stack would likely include not just the conventional "Airplane Mode" found in phones now (a switch to power off components the radio in the device during aircraft flight, as required by Federal Aviation Administration rules), but also potentially a "Car Mode" switch as well. In the future, setting a mobile device into "Car Mode" would replace the user interface with one more suitable, locking out all components that may ostensibly be deemed distracting to the driver. The National Highway Traffic Safety Administration is currently conducting an evaluation of different cell phone interfaces to determine the relative exposure of the different types of interfaces and the relative risk of each when used while driving. NHTSA expects to increase the overall understanding of driver interaction with technology, and to better understand the needs of the driving population, while identifying improvements for current vehicle systems.

One key gateway function is to apply the appropriate driver interface to both the head unit and the connected mobile device to eliminate risk of driver distraction. Potentially distracting control functions can be locked out of mobile devices in the vehicle and within the vehicle head console. Companies like Airbuity and ZoomSafer seek to specialize in customizing driver interface "policy" management that can change based on who drives, where, what, for what purpose, etc.. Driver interface policy can vary and by equipment (make, model, year, geography) based on OEM guidance or controls (or in the case of fleet vehicles, operator policy). These policy controls will likely reflect government guidelines, rules or laws of the different jurisdictions the vehicle may operate in as well.

Besides gateway functions that mange the driver vehicle interface, other gateway are needed to establish hardware and software interoperability for embedded devices that rely upon wireless services. The disaggregation of the telematics service supply chain, just starting with the application layer, has been happening slowly in the value chain focused on embedded automobile telematics hardware-centric wireless services. As far as choice of wireless technology, the ideal vision is to have vehicles communicating using any system that is available and secure, or if multiple systems are available, choosing the most direct, unencumbered, efficient or cost effective path based on the technical requirements of the application and the business needs of the application service provider. To that end, MNO's have begun to establish, through partnerships with telematics providers, application- or platform-specific machine-to-machine (M2M) terminals and shared network infrastructure. MNOs are fast-tracking certification of many new connected terminals beyond consumer handsets, such as electric utility meters and telematics units. Furthermore, multiple MNOs supply Mobile Virtual Network Operators (MVNOs) who do not own their own network base stations with wholesale airtime that encompass multiple coverage areas, stitching together a wide nationwide coverage footprint. MVNOs sell wholesale airtime as a retail service to their M2M subscribers in bulk provision and activate M2M terminals in large, scalable batches for large enterprise clients.[25]

Integration of On-Board and Cloud Data through Vehicle Gateways

The gateway in a vehicle is typically a telematics unit that provides wireless interfaces with the driver's mobile devices through Wifi, ZigBee or Bluetooth, and embedded radios that may include cellular (typically 2G) terminals. There are other intra-vehicle networking systems as well, such as the Vehicle Controller Area Network (CAN), and wireless systems, such as Tire Pressure Monitoring System and Wireless Keyless Entry. Future vehicles will also include Vehicle Dedicated Short Range Communications for inter-vehicle communications at high speeds for collision avoidance systems and mobility application. Data is generated "on-board" the vehicle from between 40-50 sensors and 30 electronic control units in a vehicle with nearly 200 lb (91kg) of wiring in today's vehicles connecting them. "Off-board," or data from the cloud arrives through the embedded cellular modem, or from a 3G/4G mobile device that is tethered to the telematics unit via WiFi or Bluetooth or some other local area or personal area networks technology.

Other sectors such as tele-health care, home automation, industrial supervisory control, and energy management are leading the way in the creation of device gateways that integrate data from multiple devices for aggregation and transmission to remote servers. For example, gateway wireless nodes, such as a smart utility meter, internet cable TV top box, or even a tethered 3G/4G mobile phone in a home can connect, without user configuration or other human intervention, to multiple devices to administer them and collect their data in the home.[26] These gateway devices in the future will aggregate many devices via a local area network using Wi-Fi, Zig-Bee, Bluetooth or some other short range communications technology, which connects to the wide area 3G/4G mobile or fixed broadband network gateway. For home area networks, gateways will monitor appliances' energy consumption patterns to recommend optimized power savings, or a home health monitoring systems that sends blood pressure, glucose readings or other medical telemetry from medical devices to a telehealth service provider network to monitor vital signs and update electronic health records.

Typically these gateway nodes enable direct or indirect command, control and security of multiple devices with a wide variety of operating modes, even translating protocols where a device may not be IP based. Command and control of the device may include activation, deactivation, diagnostics and firmware updates, as well as operating commands. For example, a device such as a baby monitor may need a mobile phone interface to send operational commands securely to turn on and off the monitor, as well as security updates to ensure the device cannot be compromised by an attacker. A number of these device management and gateway standards are being developed in organizations such as the Open Mobile Alliance, Zigbee Alliance, Telecommunications Industry Association or other industry sector specific standards or coordination bodies. Standards activity focuses on harmonizing around common information models (schema or vocabulary) and common process to provision, activate, manage and update a device, understanding that these processes need to be completed with no human intervention and able to perform under circumstances where the device might be malfunctioning or otherwise partially or fully out-of-service.

Vehicle-centric embedded gateway and device management standards are typically developed within the automotive industry and access and management of these gateways, unlike home automation and consumer electronics, is generally restricted to the auto manufacturer or qualified service provider. The Vehicle CAN is a bus that manages different control units such as body (windows and doors), dashboard instrumentation or convenience/telematics, chassis, and powertrain. These buses are typically isolated from each other to ensure resiliency, especially for safety critical systems such as Air Bags. However, there are gateways between these systems that are fire-walled with sophisticated packet content filtering. [27]

Some of these gateways from the CAN data bus system to other external interfaces can be used by vehicle diagnosis, testing and information systems like the dealer tools. Diagnostic procedures rely on querying these different pieces of electronic control units for troubleshooting, reporting, and parameter tuning. The *On Board Diagnostic* (OBD) standards define how the diagnosis can be performed. Each Control Unit has a set of *Diagnostic Trouble Codes* (DTC) that can help in identifying its status or eventual failures. Actual diagnosis is performed by a technician connecting a probing device to a specific plug inside the vehicle and performing analysis. In many vehicles, the OBD connector (currently usually compliant to OBD-2 standards) is within reach from the driver seat and allows access to at least one of the vehicle CAN buses. Ultimately, data from the CAN passes gateways to the OBD-II interface and on to the telematics units. These interfaces are typically supported by telematics service providers such as OnStar or "white-label" providers such as ATX/Cross Country.

The telematics unit, acting as a gateway to exchange on-board and off-board data, will either directly or indirectly support a number of convenience, mobility and safety applications that either run in the vehicle or are hosted on a mobile device or "off-board" on a remote servers. The data chain may cross several domains, including vehicle, mobile device and remote server. For example, Vehicle-to-Vehicle forward collision warning systems may detect a crash or even a "near crash," or a telematics system may detect fault code in a critical vehicle component and automatically activate the electronic data recorder and send an alert off-board to a server for further analysis. A fault detected in a vehicle system, such as an ignition system that is about to fail, can be transmitted to the dealer or fleet manager to be assessed and parts and repairs can be ordered prior to the system failing.

The telematics terminal, or even possibly a tethered wireless mobile device, may in the future provide the final hop to the server via the cellular network. Ultimately, the vehicle telematics gateway will exchange data across multiple vehicle functional domains to provide a complete operational picture of the performance of vehicle equipment and drivers. Relaying this data off-board to be analyzed and reported back to the driver at the conclusion of the trip can provide important feedback to improve his or her productivity and safety.

Conclusion

The Global System for Mobile Communications (GSM) Association predicts that there will be nearly 50 billion connected terminals by 2025, almost ten times the world's predicted human population. Around three-quarters to one billion of these terminals will likely be automobiles. Automotive engineers designing connected systems will face a plethora of wireless technology options for vehicles that provide short range, long range and even regional and global connectivity. Future vehicles will likely be aggregators of different devices, such as mobile app phones, tablet computers, personal navigation devices and other aftermarket devices that are brought-in. Similar to applications used in the telehealth field currently, different telematics applications will need to go through rigorous certification process to ensure that devices function in a way that is consistent with safe and secure operation of the vehicle.

The success of telematics is riding on the ease of use and practicality of integrating multiple generation technologies, from portable personal devices to machine embedded equipment. It must, however, be done in a manner that reduces costs and complexity and meets basic needs of drivers for connectivity, beyond infotainment and mobility, extending to vehicle diagnostics, occupant crash protection, and crash-avoidance.

What the future holds for wireless technology, in particular the communications infrastructure expected to be in place from 2015 onward, is speculative, but the broad outlines of what might be available are visible today. Connected vehicle applications are set to explode in the next couple of years because of the development of mobile application platforms such as Google Android and others, and enterprise machine-to-machine support services. The support of these platforms beyond 2015 will be from 4G Long Term Evolution (LTE) wireless and its progeny. Automotive application developers will need to be cognizant of how application data is treated by 4G systems, and how innovations such as "traffic shaping" may improve quality of service for "off-board" (or "cloud" based) vehicular applications.

Furthermore, "on-board" vehicular applications utilizing vehicle-to-vehicle, vehicle-to-infrastructure communications, and for safety applications, Dedicated Short Range Communications/Wireless Access for Vehicular Environments (WAVE) may also likely be integrated into 4G to provide diagnostics and maintenance functions. Later versions of LTE, such as *LTE Advanced,* may establish and manage communication sessions that hop between many of the previously mentioned wireless technologies, a concept known as heterogeneous or "vertical" roaming.

LTE will likely not have national coverage for some time beyond 2015 and deployment will likely start in urban areas first. Many in the wireless industry have talked of a targeted deployment strategy known as "inside-out" deployment. The "inside-out" strategy has LTE first in homes and offices with 3G/4G/WiFi femtocells, then 4G macro-base stations in major metropolitan areas, then expanding 4G outward to other cities and rural areas. Deployment of femto cells in urban areas especially may be near or within the right-of-way of highway facilities to provide improved coverage for highway users. Development of new network infrastructure technology, such as self- organizing cells and vertical roaming, may be determining factors in the success of femto cell deployment.

Many of these peer-to-peer wireless systems found in future vehicles will likely interact closely with 4G, supporting each other to authenticate users for secure use of safety-critical "cooperative" applications, such as vehicle-to-vehicle collision avoidance, or to run diagnostics to ensure proper functioning of all vehicle or infrastructure-based safety and mobility applications. DSRC/WAVE units, however, are expected to utilize wireless backhaul to the cloud, likely through cellular or possible dedicated wide area networks. Future vehicles and roadside systems such as traffic controllers will likely be installed and operating DSRC/WAVE based applications such as electronic brake lights or intersection collision warning, but will also utilize wide area connections to the cloud to support some basic vehicle and roadway system diagnostics and maintenance wherever necessary.

4G terminals in vehicles may even off-load data traffic opportunistically (possibly at reduced tarrifs) to short range 4G femto cells, Wi-Fi and perhaps even DSRC/WAVE nodes in urban areas. DSRC/WAVE and WiFi may provide a number of inexpensive options to vehicle applications to offload data or communicate to “the cloud.” Ultimately, automotive electronics engineers will need to recognize these possibilities and anticipate trends in wireless infrastructure to develop compelling, reliable and cost effective vehicle-oriented applications.

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[1] The author is indebted to a number of experts that provided advice and comments in discussions on the topic: Sheryl Wilkerson (Automotive Aftermarket Industry Association), Ralph Robinson (University of Michigan), Bakhtiar Litkouhi (General Motors), Craig Copland (ATX/Cross Country), Rebecca Hanson (Federal Communications Commission), Upkar Dhaliwal (Future Tech Wireless), Rod MacKenzie (Harmon/AHA mobile) and Dave McNamara (McNamara Technology Solutions). The conclusions and opinions expressed in this report are the authors only.

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