Appendix-16

Report on 5G and OBDII Updates

Impacts of OBDII Updates and 5G on Road Charging

Version 3b

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Contents

Figures

Revision History

VERSION	MAIN CHANGES	CONTRIBUTIONS FROM	DATE
V01a	Development of First Draft	M Dorfman	20160620-26
V02a	Addition of 5G content	S Crum	20160627
V03a	Internal Review and Quality Control	S Morello	20160528-29
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Executive Summary

This report provides a summary of the impact of the Air Resources Board's staff proposal for the 2015 amendments to the OBD II regulation on the ability for information obtained through the OBD II system to support assessment of a road charge, and possible longer-term implications of emerging 5G mobile communications for road charging. This report describes the historical background for establishment of the OBD II system within vehicles operating in California, the use of OBD II data for road charging (charging by mile traveled), a description of the proposed 2015 OBD II amendments relevant to a road charge, and an analysis of the effect of the regulations on assessment of a road charge. It then describes constraints imposed by currently available mobile communications standards and presents a road charge use case for the 5G standard.

The OBD II systems were developed as an emissions control mechanism. Nearly every vehicle sold in the United States is designed and certified to California's OBD II regulations. From the start, vehicle data generated by OBD II systems has been used for purposes other than emissions control. Ten years ago, around 2006, state governments in the US began using OBD II data to obtain vehicle mileage information to test collection of a per mile road charge as a replacement of the current road funding mechanism based on fuel taxes. In various tests, the state of Oregon used mileage counting devices or mileage meters (called dongles) plugged into the OBD II port to access data for reporting miles driven and fuel consumption. Successful tests in Oregon led to passage of a law enacting the Oregon Road Usage Charge Program, called ORe*GO*, an operational system collecting actual money and refunding gas taxes. While generally successful, ORe*GO* has experienced challenges in ensuring accurate reporting of data, in particular (a) when the mileage meters are removed from vehicles and (b) due to the non-standardization of fuel consumption related data across vehicle models.

In 2015, the California Air Resources Board proposed several amendments to the OBD II regulations which will be phased in to production vehicles over a three-year period beginning with the 2019 model year. The proposed 2015 amendments will allow road charging systems to acquire certain new data helpful for assessing the road charge. Prior to these amendments, to compute distance traveled from OBD II data, vehicle speed data was used because cumulative distance data (e.g., a copy of the vehicle odometer) was unavailable. Similarly, while some vehicles provided data which could be used to compute instantaneous fuel consumption, roughly 25% of vehicles did not provide this data, and very few vehicles provided cumulative fuel consumption. The 2015 amendments would require all vehicles to electronically report and store cumulative distance traveled and cumulative fuel consumed. Also, until now, the location requirement for the OBD II port (data link connector) was to be somewhere near the vehicle steering wheel, but the new 2015 amendments would specify standard locations for the OBD II.

The proposed new requirements for storage of aggregate miles traveled means that mileage traveled data will not be lost when a mileage meter is removed from the ODB II port. While mileage traveled may not be reported by a mileage meter when it is disconnected, the mileage can be transmitted as soon as the device is plugged back into the connector. Even so, vehicle location data are not recoverable this way because location data is not available on the OBD II data feed. Accordingly, a mileage metering device, once unplugged, will not be able to determine whether miles driven are chargeable or non-chargeable when the device is plugged back in, even if the mileage meter itself uses location information.

Impacts of OBDII updates and 5G on Road Charging

This new requirement is highly beneficial to the accuracy of road charges and fuel tax credits because they reduce the ability to cheat and reduce the cost of managing situations where miles or fuel data are missing due to disconnections of a mileage meter.

To accommodate the anticipated explosion of connected devices for everyday use, development standards for 5G mobile communications are currently underway. The 5G standard has great potential to support vehicle connectivity with applications in road charging by reinforcing creation of a transportation utility ecosystem allowing a single integrated terminal to support multiple in-vehicle activities and all data transmissions.

The 5G mobile communications standards could eliminate the need for after-market OBD II dongles, offer better connectivity, a more streamlined experience for drivers, ability to handle millions of vehicles, identification of taxable jurisdiction in real time, and reduced operating expense for a road charge system. The International Telecommunication Union is not expected to publish the final 5G specification until 2020. Commercial deployment will occur in the post-2020 timeframe.

1. Introduction

Two pending modifications to existing standards have great potential to improve road charge data collection and reporting. In the near-term, amendments by California Air Resources Board to the current vehicle on-board diagnostic system standard (OBD II) would add data elements that directly support assessment of road charges on fossil-fuel powered vehicles. In the longer term, the still-developing 5G mobile communications standard could eliminate the need for after-market OBD II dongles, reduce road charge operating expenses, and expand the range of consumer and safety applications that could be offered as part of road charge account management services.

1.1. Background on OBD II Regulations in California

In response to poor air quality in California metropolitan areas and the requirements of the federal Clean Air Act, the Air Resources Board adopted emissions standards and requirements for equipping engines of passenger cars, light duty trucks and medium duty vehicles with on-board diagnostic systems (referred to as OBD II). The requirements were phased in starting in 1994, and applied to all 1996 and later model years sold in California and nationwide, due to the US Environmental Protection Agency (EPA) basically copying the OBD II regulation as a national regulation. The Air Resources Board updated the OBD II regulations several times, notably for 2004 and later model years. The Air Resources Board last updated OBD II requirements in 2012 and 2013.

Primarily comprised of software within the vehicle's on-board computer system, the OBD II systems provide basic vehicle data over the OBD II port and detect malfunctions in the emission control system by monitoring components and systems that affect emissions. An OBD II system detecting an equipment malfunction alerts the vehicle owner by illuminating the malfunction indicator light on the dashboard, commonly known as the "Check Engine" light. The OBD II system also stores information about the malfunction to enable technicians to correct it. OBD II systems report this data in a standardized format for processing and reading by scan tools that plug into vehicles' OBDII ports.

1.2. Purpose of this Report

The purpose of this report is to summarize and assess implications of the proposed new OBD II regulations and developing 5G mobile communications standard for road charge policies under investigation in California in accordance with recommendations adopted by the Road Charge Technical Advisory Committee (TAC) pursuant to SB 1077 enacted by the California Legislative Assembly and signed by Governor Jerry Brown in 2014. The first part of this report focuses on proposed new data parameters for the OBD II system and how they affect technologies currently or potentially used for reporting distance traveled, to apply a road charge rate, and fuel consumption to calculate a credit for fuel tax paid. The second part focuses on developing mobile communications standards, particularly on their implications for improving accuracy, reducing operating cost, and improving ease of use by integrating road charge with other in-vehicle communications systems.

1.3. Organization of this Report

The report is organized as follows:

- Chapter 2 provides a brief history of the OBD II system.
- Chapter 3 describes use of the OBD II system for road charging and usage-based insurance.

- Chapter 4 summarizes the proposed OBD II amendments purpose, the relevancy for road charge reporting and concerns addressed by the ARB staff.
- Chapter 5 explores the impact of the proposed OBD II amendments on future use of OBD II systems for the road charge.
- Chapter 6 describes limitations imposed by current mobile communications standards (3G and 4G/LTE) and introduces the 5G mobile communications standard.
- Chapter 7 develops a road charge use case for 5G.
- Chapter 8 provides conclusions.

2. A Brief History of the OBD II System

An on-board diagnostic system (OBD) is a system by which a vehicle self-diagnoses and reports the health of its various subsystems. The nature and amount of diagnostic data accessible through the OBD has varied since its first application.

Developed and used beginning in 1980, the first legally mandated on-board diagnostic system (now known as OBD I) monitored some, but not all, of the vehicle's electronic and mechanical functions. OBD I lacked a requirement for standardization among different vehicle makes and models. Because each automaker's OBD I system was proprietary, development of a generic scanning tool for accessing data from all vehicles was impossible.

Desire for a more sophisticated on-board diagnostic system for vehicle emissions reporting led to development and adoption of the OBD II system by the Air Resources Board. The OBD II system is standardized throughout all fossil fuel burning vehicles sold in the US. In addition to being standardized, OBDII detects a host of additional emissions-related problems not detected by OBD I systems, such as progressive deterioration of emission control equipment.

The first tests of OBD II systems occurred in 1994 with general application to all light vehicles in 1996. Changes to OBD II regulations led to alteration of the functional capabilities of the OBD II port in ensuing years.

The purpose of OBD II systems is to facilitate the maintenance of emission standards over the vehicle's life. The OBD II systems do not achieve this goal because they do not prevent vehicles from being operated when they have emission issues. Currently, resolution of emissions-related issues is accomplished through a vehicle owner's prompt response to activation of the "Check Engine" light and through mandatory periodic vehicle emissions testing such as the California Smog Check. Because vehicle owners tend not to consistently respond quickly to the "Check Engine" light, and because smog checks do not occur frequently, the emissions reduction potential of the OBD II system underachieves. Further, the OBD II regulations do not guarantee a direct linkage between the automakers' vehicle emissions test data and actual emissions performance of the vehicle.

To improve vehicle owner response time to the indicator light, officials have developed a concept for "OBD III" regulations to allow remote reporting of vehicle data. Such regulations are not included in the 2015 amendments, in part because automakers have opposed these more far-reaching steps, and in part because of privacy concerns. If eventually adopted, remote OBD data reporting would increase effectiveness for addressing vehicle emissions health, reduce the cost and time of on-site vehicle testing and improve air quality.

3. Current Use of OBD II for Road Charge and Usage-Based Insurance

Since the standardization of the OBD II system, the vehicle data it generates has been used for purposes other than emissions control. Commercial entities have developed plug-in devices to access relevant vehicle data via the OBD II port. Such devices, called scan tools or dongles, access the OBD II data for a range of purposes such as corporate fleet monitoring and usage-based automobile insurance (UBI). Beginning in 2006, state governments in the US began accessing vehicle mileage data through the OBD II system to test collection of a per mile road charge to replace the fuel tax as a road funding mechanism.

3.1. Use of OBD II Data for Usage Based Auto Insurance

Several auto insurance companies have had significant success changing their business model by evaluating vehicle and driver behavior data from an insured vehicle over the OBD II port. By using a small scan tool that has GPS location capability plugged into a OBD II port, the insurance company can monitor the number of miles driven per day, the time of day the miles were driven, where the miles were driven and other driver behaviors such as acceleration and hard-breaking. In this manner, the insurance company determines which drivers are greater or lesser insurance risks, and adjust premiums accordingly. Enforcement generally is not an issue for UBI policies because the driver generally plugs the scan tool into the OBD II port only for a limited behavior evaluation period although sometimes the duration is for the length of the policy. Potentially manipulative behavior, such as unplugging the scan tool for extended periods, can be easily identified and will affect the policy issuance decision.

3.2. Use of OBD II Data for Charging by the Mile

In the 2007 Road User Fee Pilot Program, Oregon's DOT accessed participating vehicles' OBD II systems to report vehicle miles traveled. Through a mileage counting device plugged into the OBD II port that interacted with a separate GPS receiver, the Oregon DOT was able to determine time and place of miles driven. Using this information, the DOT computed and collected a road charge from volunteer participants and also conducted a separate but aligned congestion pricing experiment by charging a higher amount for travel in the urban core of Portland during peak periods. In 2009, the University of Iowa completed a study using a mileage reporting method similar to Oregon's 2007 study.

In the 2013 Road Usage Charge Pilot Program, Oregon used OBD II plug-in devices, with and without a GPS chip, to access the OBD II system for reporting miles driven and fuel consumption. The Oregon DOT contracted with private sector account managers to collect mileage data and the per mile charge with a credit for fuel tax paid.

Success for Oregon's 2013 test led to passage of a law enacting the Oregon Road Usage Charge Program, an operational system collecting actual money and refunding gas taxes to those who participate. Branded as ORe*GO,* the program launched on July 1, 2015 using certified technologies provided by several private sector account managers to access data through the OBD II system. ORe*GO* certifies data scan tools to access the OBD II data of participating vehicles. One requirement imposed is use of a standard message format for transmission of data.

3.3. Challenges for Mileage Reporting Using OBD II System

Reliance on the OBD II system for mileage reporting has drawbacks. There are challenging issues pertaining to enforcement, fuel consumption reporting and application to vehicles starting in electric mode.

3.3.1. Enforcement

Enforcement issues arise in an OBD II based road charge system when drivers disconnect the device from the vehicle. In ORe*GO*, the road charge system cannot determine the number of miles unreported when a device is disconnected from the OBD II port. That is because the missing mileage is not stored within the vehicle's computer system. As an enforcement measure in a potential future mandatory road charging system, ORe*GO* could, based on the length of time which an OBD II device was unplugged, impose a charge calculated based on an average mileage for a period when mileage actually was reported. An alternative measure for enforcement of cases in which an OBD II device was unplugged for an extensive period of time could be performance of a relatively expensive audit. Neither of these is an ideal means of providing enforcement in a mandatory road charge system.

3.3.2. Fuel Consumption

Currently, fuel consumption reporting in an OBD II system is not standardized. Using OBD II data, fuel consumption can be fairly accurately computed for about 75% of vehicles. For the other 25% of vehicles, fuel consumption cannot be computed in this manner. For these vehicles, a fuel consumption estimate can only be determined by multiplying the EPA estimated fuel economy by the number of miles driven—a fairly imprecise method. Moreover, fuel consumption data, like mileage data, cannot be determined for any vehicle while an OBD II device is not plugged into a vehicle.

3.3.3. Start up Issues for Vehicles in Electric Propulsion Mode

Currently, operative OBD II ports are not required for electric or hybrid electric vehicles operating in electric mode. As a result, mileage metering devices plugged into the OBD II port have not consistently started as soon as the vehicle starts, and thus may miss mileage on hybrid vehicles traveling in electric propulsion mode. In Oregon, Ore*Go* account managers have developed work-arounds for many hybrid electric vehicle models, but the application is not uniform and the development process tedious. Note that electric vehicles are not legally required to have OBD II ports because they are zero emission vehicles and the OBD II enabling legislation only provides legal scope for creating regulation on vehicles that cause emissions.

3.3.4. Installations of Dongles into OBD II Data Link Connectors

Installation of data reading devices into OBD II ports is a simple and easy process once the port is located. Regulations require placement of the port near the steering wheel, but the exact location is not standardized, leading a few vehicle models to provide the ports in inconvenient locations. Some OBDII ports have covers which can be unwieldy to remove and may make it hard for a driver to find the OBD II port.

4. Summary of Proposed OBD II Amendments

Working with stakeholders, including automobile manufacturers, to address implementation issues from the last issued OBD II regulation and alignment with new policies for low emissions vehicles, the Air Resources Board staff proposed amendments to the OBD II regulations in September 2015.[1]

4.1. Purpose of Proposed OBD II Amendments

The primary purpose of the 2015 amendments is to "ensure the integrity of OBD II systems" by, among other things, incorporating new requirements adopted in federal OBD II regulations and California's 2012 low emissions vehicle III program, including prescribing emission malfunction thresholds for certification of low emission vehicles. These thresholds function as maximum allowable emissions limits. At the point emissions exceed these limits, OBD II systems must detect malfunctions in specified vehicle components or systems.

A secondary purpose for the 2015 amendments is to require new real-time data stream parameters for reporting through OBD II systems to validate automaker claims about vehicle fuel emissions. These amendments will allow automaker testing of vehicle emissions control measures, such as vehicle technology and aerodynamic improvements, to be quantified as actually delivering expected greenhouse gas benefits and consumer fuel savings in the real world. In justifying these changes, Air Resources Board staff cites recent instances in which the federal government required vehicle manufacturers to re-label certain vehicle models with lower fuel economy than originally claimed.

4.2. OBD II Amendments Relevant to Road Charge

The 2015 amendments are highly relevant to use of the OBD II system for data acquisition necessary for a road charge. There are two sets of new requirements, one for all vehicles and the other for plug-in hybrid electric vehicles. Both sets of requirements will be phased in over a three-year period beginning with the 2019 model year These new requirements are significant because historically nearly every vehicle sold in the United States is designed and certified to California's OBD II regulations. While 2015 amendments apply across the board to all makes and models, only volunteers will report the new data to the Air Resources Board for purposes of constructing the real world emissions data check on manufacturers' certification test data.

4.2.1. Proposed Requirements for All Vehicles

For all vehicles, the 2015 amendments would require the OBD II system to electronically report and store cumulative distance traveled (staff referenced as "electronically provide the odometer reading") and cumulative fuel consumed. These data would quantify actual CO_2 vehicle performance for a direct comparison to data generated during certification testing. The data would not include any information that could be used to identify a vehicle's location either currently or in the past.

In order to ease the emissions scanning process, the new 2015 amendments would specify standard locations for the OBD II port within all vehicles beginning in 2019. Additionally, the amendments prohibit the use of covers for OBD II ports.

[1] California Air Resources Board, Clean Version of Latest Office of Administrative Law-approved version of OBD-II regulations, Approved July 25, 2016, available at: https://www.arb.ca.gov/msprog/obdprog/section1968_2_clean2016.pdf

For plug-in hybrid electric vehicles, the new data regulations would require the following parameters:

- Cumulative distance traveled while depleting the vehicle's electric charge (measured separately with the engine off and the engine on);
- Cumulative distance traveled while increasing the vehicle's electric charge;
- Cumulative fuel consumed while depleting the vehicle's electric charge;
- Cumulative fuel consumed while increasing the vehicle's electric charge; and
- Cumulative grid energy consumed while depleting the vehicle's electric charge (measured separately with the engine off and with the engine on).

4.2.2. Storage of the New Data

The 2015 amendments would require storage of the new data in aggregate format, not time or trip specific, within one of the vehicle's onboard computers used for engine control. The stored data must not contain information about the manner of the driver's operation of the vehicle.

4.3. Erasure of New Data Parameters

To reduce the opportunity for selective reprogramming events to evade indications of detected faults in emissions control equipment, the 2015 amendments would specify that certain information from diagnostic or emission critical control units must be erased in the event of a scan tool command or power disconnection to the on-board computer. Among the information that would be erased under these circumstances is data stream information, including distance traveled and run time.

4.4. Availability of New Data Parameters

The proposed 2015 amendments specify that the new data parameters are available to the vehicle owners, repair technicians and vehicle manufacturers.

4.5. Concerns Addressed by the OBD II Amendments

In large measure, the structure of the 2015 amendments for real-time data stream parameters directly relates to a staff hesitancy to encroach upon motorists' privacy. This led to elimination of possible data parameters that could identify a person. Thus, no location data will be stored or reported. Data content will be stored only in the aggregate. The data will only quantify vehicle performance and not driver performance. Only data from voluntary participants will be collected for the real world verifications.

5. Impact of Proposed ODB II Amendments on Future Use of OBD II Systems for Road Charge

5.1. Reporting and Storing Aggregate Miles Traveled for All Vehicles

The proposed new requirement for providing cumulative miles traveled on the OBD II port provides any plug-in devices ready access to total miles driven immediately upon plugging into the OBD II port. This means that miles traveled will not be lost when a mileage metering device is removed from the OBD II port. Since miles traveled cannot be reported while the device is disconnected, as soon as the given device or another device is plugged back into the connector, total miles traveled while the device was unplugged can be transmitted to whomever calculates the road charge.

Storing miles traveled in the aggregate without location means that any non-chargeable miles (off-road, private road, out-of-state) will remain unidentified when the removed scan tool is plugged back into the connector. Thus, for motorists selecting location-based mileage reporting, all recovered miles would be assessed as chargeable, due to the lack of differentiation of non-chargeable miles. Policymakers will have to decide whether to allow manual refunds of non-chargeable portion of the recovered miles based on other evidence. Nevertheless, the vehicle owner has the responsibility to maintain a functioning mileage reporting mechanism, so policymakers may simply require assessment of *all* recovered miles as chargeable—without providing any adjustment for non-chargeable miles traveled.

This new requirement is highly beneficial to the accuracy of road charges by reducing the ability to cheat (drive while the mileage counting device is unplugged) and reducing the cost of managing situations where miles are missing owing to disconnections. It also removes one of the major objections to the OBD II device-based method of road charge reporting. This objection—that the system is susceptible to fraud when devices are removed from a vehicle—is frequently raised by opponents of road charges and those yet to be convinced about the viability of charging by the mile.

5.2. Reporting and Storing Fuel Consumption for All Vehicles

The proposed new requirement for standardized reporting of fuel use in all vehicles corrects inconsistencies in this regard under the current OBD II system abilities. Now all vehicles will be able to report fuel consumed in the same way. This will make crediting fuel consumption as an offset to the road charge accurate and simple while eliminating motorist angst over the current inconsistent and often inaccurate capability.

5.3. Effect of New Data Parameters for Hybrid Electric Vehicles on Road Charge

The new data parameters for hybrid electric vehicles do not impact or improve the ability of a road charge system. These data parameters relate directly to determining the real world fuel and electric efficiencies of particular models in this category of vehicle. Reporting the cumulative distance vehicles travel on an electric charge, the amount of fuel consumed while increasing an electric charge and the amount of grid energy consumed while the vehicle travels, could allow different rates to be charged depending on whether a vehicle is operating in fuel or in electric mode, but this is not currently a desired feature of a road charge. Such information is not otherwise relevant to collection of a road charge.

5.4. Erasure of New Data Parameters

An exception to availability of stored aggregate miles traveled is that under certain events—a power loss to the emissions control unit or a scan tool command—the miles traveled information will be erased from the vehicle's emissions control unit. These events do not seem to be a common action and therefore should have minimal effect on enforcement of a road charge unless these measures introduce an as yet undetermined method for potential fraud activities. Even so, fraud attempts using such methods should be able to be easily identified, making the impact of such activities fairly small.

5.5. Availability of New Data Relevant to Road Charge

Since the new OBD II data parameters are available to owners who will select an OBD II mileage reporting mechanism from a number of reporting options, data relevant to a road charge will be available as factors used in a road charge assessment.

6. Next Generation Mobile Communications

6.1. Current Use of Mobile Communications for Road Charge

Recent road charge demonstrations in the US have revealed that privacy protection, reliability of measurements, accuracy, cost-effectiveness, and ease of use will be critical elements of any successful large-scale implementation of road charge. These demonstrations have employed various combinations of after-market mobile-integrated OBD II dongles, dongles and smartphones paired with Bluetooth© tethers, RFID tags, untethered smartphone apps, mobile-equipped GPS antennae, and native telematics systems, all with varying degrees of success. Each of these technologies currently uses either 3G or 4G communications standards to transmit road charge data elements (mileage driven, location, fuel consumption, etc.) to account management systems.

The various demonstrations support the argument that after-market devices function adequately as mileage meters, but their reliance on 3G or incompletely-implemented 4G mobile networks imposes limitations on mobility, data transmission speeds, ease of use, and reliability. Further, current technology typically requires some physical connection of metering devices to the vehicle via the single OBD-II port. This means that consumers must choose between services such as usage-based insurance, RUC, teen-driver monitoring, etc. because only one device can be plugged in at a time. All devices must be removed while the vehicle is being serviced. Data transmission costs are a limiting factor in the ability to fully leverage native vehicle telematics, and contribute significantly to ongoing operating expenses in any road charge network.

Research underway to support the emerging 5G standard suggests that in the near future mileage metering can be integrated with a host of other vehicle information services, simplifying the process and significantly reducing the cost of collecting and reporting mileage data while also eliminating the requirement for physical connections to the vehicle, improving mobility, dramatically increasing data transmission speeds, and raising the reliability of mobile connectivity to greater than 99 percent.

6.2. 5G

While 5G is widely described as the next generation in mobile telecommunications technology, it is in fact a sizeable collection of technologies and standards, some of which have not yet been invented or written. However, a number of industry and research groups have been collaborating for several years to define core goals for the 5G standard[2,3], and the US Federal Communications Commission (FCC) is scheduled to vote on dedicating high-band spectrum to 5G applications in July 2016[4]. The evolution of mobile communications standards from 1G (analogue voice communication) to 5G is illustrated in Figure 1 below.

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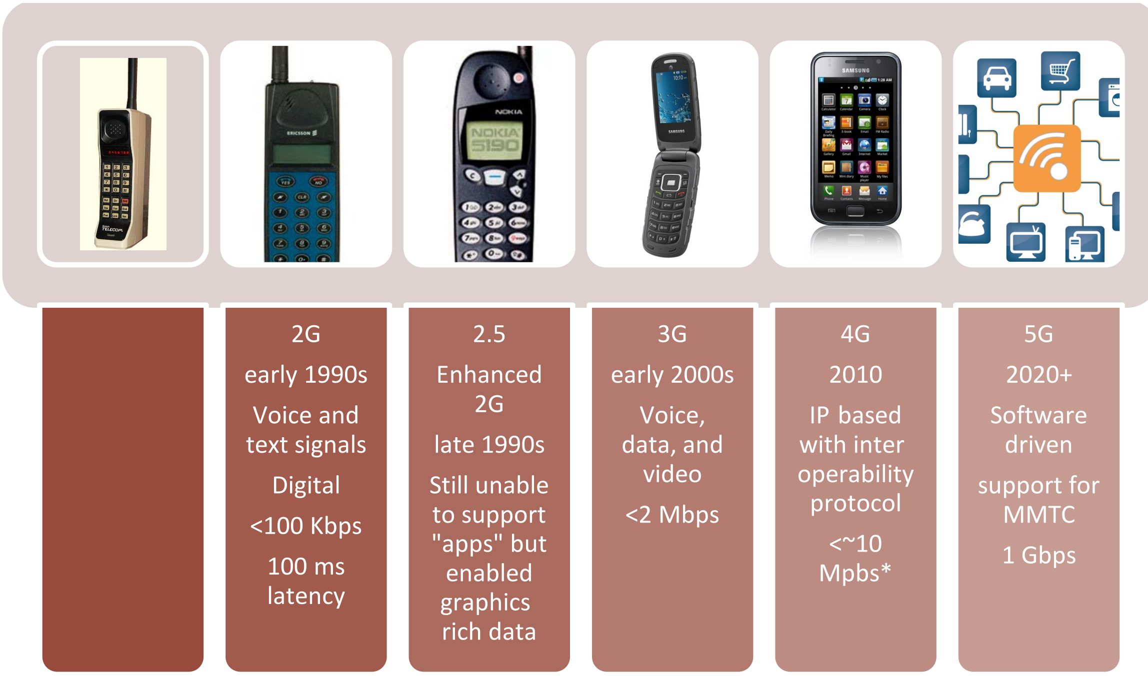
[2] 5GPPP. (2015). *5G Vision Brochure.* Retrieved December 18, 2015: https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf.

[3] Young, L. J. (2015). Telecom experts plot a path to 5G [News]. *Spectrum, IEEE*, *52*(10), 14-15.

[4] Loughran, Jack. (June 21, 2016). 5G Spectrum Space Freed up by FCC in USA. *Engineering and Technology Magazine.* http://eandt.theiet.org/news/2016/jun/fcc-5g-spectrum-america.cfm. Retrieved June 22, 2016.

Impacts of OBDII updates and 5G on Road Charging

Figure 1: Evolution of Mobile Communications



6.3. Why Develop a New Standard?

The primary force driving development of the 5G standard is the anticipated explosion of connected devices including household appliances and systems, vehicles, wearable technology, wireless sensors, etc. The existing 4G architecture is limited in the number of devices any one cell can manage (anyone who has tried to make or receive phone calls in a football stadium has experienced the phenomenon of tower-overload), relatively high latency where either the radio or the cell tower are the bottleneck, inadequate data throughput for real-time interactivity, lack of support for direct device-to-device (D2D) communication, and high energy use. Further, in many countries the portion of the radio spectrum utilized by 3G and 4G is already heavily subscribed, with little room left for expansion.

6.4. Goals for the 5G Standard

While the final 5G specification is not expected to be published by the International Telecommunication Union (ITU) until 2020, industry groups, telecommunications providers, and research organizations have already established goals for the standard that include:

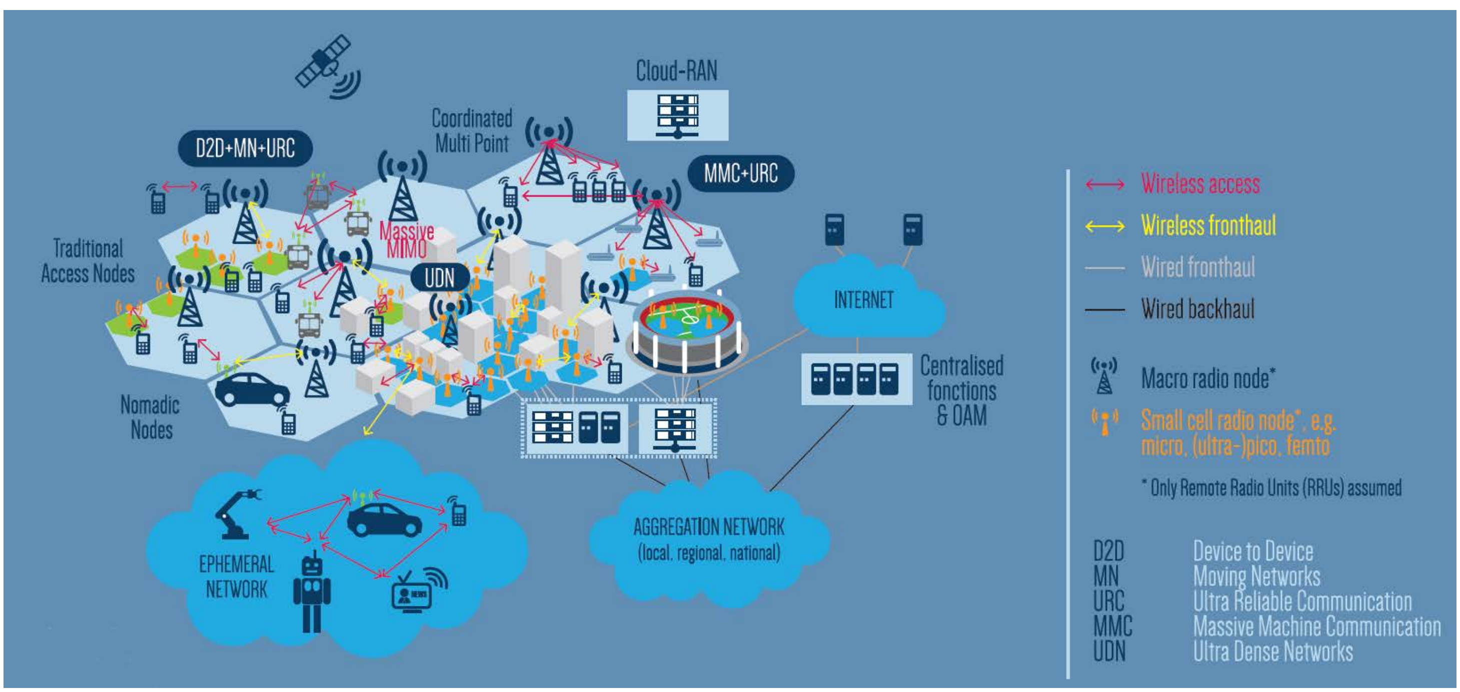
- *Guaranteed user data rate of at least 50Mbps, approaching 1Gbps for machine-type control (MTC) applications*.
- *Aggregate service reliability (ability to connect to the network) of greater than 99.9 percent*.
- *Ability to support at least one million terminals per square kilometer, representing a thousand-fold increase over 4G*. The density of machines communicating with each other under the 5G protocol is expected to be massive. As 5G is a layered technology protocol, some of this communication may be terminal-to-terminal in an “ephemeral network” (see Figure 2), bypassing a cell tower. However, the

standard assumes much of the traffic will be managed via cell tower, and so each cell will be able to support at least 1000 times the terminals as current cells.

- *Reduction of network operating expense to 1/5 of 4G costs.* The driving rationale behind this goal is to facilitate the adoption of 5G in less developed countries, particularly in Asia and Africa. However, it also benefits 5G adoption and spread in the US, since the business case to replace or augment 4G networks would be strong. As a practical matter, this is the most aspirational goal. Without significant innovation and development of new radio technologies, such a dramatic decrease in costs may not materialize in the early implementations of 5G.
- *Precise (less than one meter) geolocation capabilities for outdoor terminals.* An expected proliferation of "mini-towers" will enable the cellular network to precisely locate terminals.
- *Reduction in end-to-end latency to less than five milliseconds for most applications and about one millisecond for vehicle-to-vehicle (V2V) safety applications.*
- *Direct support for D2D and MTC communications.*
- *Mobility support at speeds greater than 500 kilometers per hour for ground transportation*.
- *Ninety percent reduction in energy consumption compared to 2010.*

The most widely discussed commercial applications of 5G range from home automation to mobile gaming to wearable technology, but 5G has great potential to support vehicle connectivity with applications in road charging by leveraging the potential for "ephemeral networks" and the proposed ultra-dense network illustrated in Figure 2.

Figure 2: Illustrative Model of Vision for 5G Networks and Services



Source: 5GPPP. (2015). 5G Vision Brochure.

6.5. Timeline for 5G Implementation

Standards development for 5G is currently underway, with the expectation that final adoption and early commercial deployment will occur in the post-2020 timeframe. However, both South Korea and Japan have indicated they plan to deploy at least of some elements of 5G earlier, first at the PyeongChang Winter Olympic Games in 2018 and then at the Tokyo Summer Olympic Games in 2020.

Mobile and information technology companies such as NTT DoCoMo, NEC, Ericsson, Samsung, and Verizon began limited field trials in early 2016, and research and development activities for the new radio technologies that will be required to fully deploy 5G have been underway in dedicated research groups since around 2008. The US has lagged in full adoption of 4G, so it is difficult to estimate when 5G could be deployed there, but Verizon is currently conducting tests with a goal of very limited deployment (mobile hotspot and fixed wireless, only) of 5G in the US sometime in 2017.

6.6. Key Elements of 5G Relevant to Road Charging

5G has the potential to reinforce the creation of a transportation utility ecosystem, of which road charging is a part, by allowing a single terminal to support multiple in-vehicle activities, including infotainment, navigation, V2X safety applications, and cloud support for vehicle automation (including driver assist and "autonomous" functions). Native support for D2D communications will enable connections among multiple wireless in-vehicle and infrastructure-based sensors for the purpose of metering road usage and, if necessary, fuel consumption and location, over wide coverage areas.

- *Guaranteed user data rate of at least 50Mbps, approaching 1Gbps for machine-type control (MTC) applications*. In a road charge context, this enables a single vehicle-based terminal to manage all the vehicle's data transmission. Rather than installing separate systems for connected vehicle safety applications, in-vehicle entertainment, usage-based insurance, road charging, and teen-driver monitoring, a single integrated terminal will be able to manage all communications inside the vehicle and serve as the point of contact to the outside world. There are direct benefits in terms of ease-of-use for motorists – in new vehicles there could be no requirement for a plug-in device if the OBD II computer is able to wirelessly communicate with the vehicle's terminal, which then transmits data to the account management service.
- *Aggregate service reliability (ability to connect to the network) of greater than 99.9 percent*. Very high reliability (greater than 99.9 percent) mitigates a significant challenge faced by current Road Charging systems utilizing 3G or 4G communications. At the present time, Road Charging participants who use an on-board device, whether it be based on OBD II dongles, smartphone, or native telematics must store data and are only able to transmit when their devices are able to connect to the network. In areas with poor cellular coverage (rural areas but also dense urban areas where "urban canyons" interfere with radio signals) data are irregularly transmitted and data loss may occur. The improved reliability and coverage promised by 5G should mitigate this issue, particularly in urban environments.

Impacts of OBDII updates and 5G on Road Charging

- *Ability to support at least one million terminals per square kilometer, representing a thousand-fold increase over 4G*. Another consideration of a fully deployed road charge system is the sheer number of vehicles that would eventually be connected under a national road charge. In the US there are more than 250 million registered vehicles, including heavy vehicles and motorcycles[5]. "Massive" Machine-to-Machine (M2M) (MM2M) refers to the ability of 5G networks to simultaneously support thousands of connected devices per base station – compared to the hundreds supported under 4G – and addresses another issue currently facing large-scale road charge deployments. Although the amount of data a vehicle must transmit to support road charge metering is quite small, support for ubiquitous road charging under a public utility model requires that millions of vehicles be supported simultaneously, and ideally in near-real time (for purposes of allocating road charges to the correct jurisdiction without collecting precise location).
- *Reduction of network operating expense to 1/5 of 4G costs.* A significant portion of operating costs for road charge methods using OBD II devices is the ongoing communications required to report road charge data. If network operating costs can be reduced significantly, it should translate to a reduction in data transmission costs, and overall lower operating costs for a road charging program.
- *Precise (less than one meter) geolocation capabilities for outdoor terminals.* An expected proliferation of "mini-towers" will enable the cellular network to precisely locate terminals. For vehicle-based terminals, this functionality could eliminate the requirement that GPS be used to determine taxable mileage or jurisdiction.
- *Mobility support at speeds greater than 500 kilometers per hour for ground transportation*.

[5] United States Department of Transportation Bureau of Transportation Statistics. (2016). *National Transportation Statistics. Table 1-11: Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances.* Retrieved January 21, 2016. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html.

7. Conclusions

The impact of the 2015 amendments to the OBD II regulations will have a positive effect on collection of data necessary for assessing a road charge. Specifically, the amendments directing standardization of reporting and storage of cumulative miles traveled and cumulative fuel consumption will resolve certain enforcement issues that have emerged for road charge systems. The amendments will also resolve consistency for providing a fuel tax credit against a road charge. In the longer term, deployment of 5G has a strong road charge use case, offering better connectivity, a more streamlined experience for drivers, ability to handle millions of vehicles, identification of taxable jurisdiction in real time, and reduced operating expense for a road charge system.