



CONNECTING VEHICLE TO FUTURE

V2I Network Solution for TOYOTA

ebConsultants LLP©

Team Fifteen Minutes

Yuheng Li, Yuanhao Chen, Nithin Donnipad
Zhonghe Yang, Kaipeng Wang, Shapan Dashore

September 27, 2015

Table of Contents



Executive Summary.....	1
Technology Overview.....	3
Application Recommendation.....	7
Network Solutions.....	35
Reference	57



Executive summary

ebConsultants is a technology-consulting firm located in Pittsburgh, PA. Our mission is to provide critical support to clients in helping form, design, and employ technologies to solve complex business problems. This report contains our expert recommendations to Toyota in using technology and wireless networks to document and utilize car and user generated data instantly and effectively to employ applications that add value to the Toyota user. The technologies and networks we employ in our recommendations allow for large data transmission dynamically and are supported by two important systems we have developed: onboard and Vehicle-to-Infrastructure communication systems. With the help of Bluetooth, Wi-Fi hotspots, Long-Term Evolution (LTE) networks, and 802.11ac networks we offer Toyota users unparalleled network and technology eco-system to be connected at all times. Moreover, our network showcases advanced features such as hardware and software level data compressions, data cache ability, and breakpoint resume capabilities. To demonstrate the complexity and innovation of our networks, we have developed the following applications: Personal

Comfort, Dependable Care, Update on the Air, My Entune, Intelligent Travel, Efficient Gas, Smart Tip, and Smart Eye. Each of these applications offer value to the Toyota customer and help Toyota create a competitive edge in the crowded car manufacturer industry. In conclusion, the network design we have proposed, along with the applications we recommend, will help Toyota transition to the next generation of user-car experience and be a pioneer in this growing field.

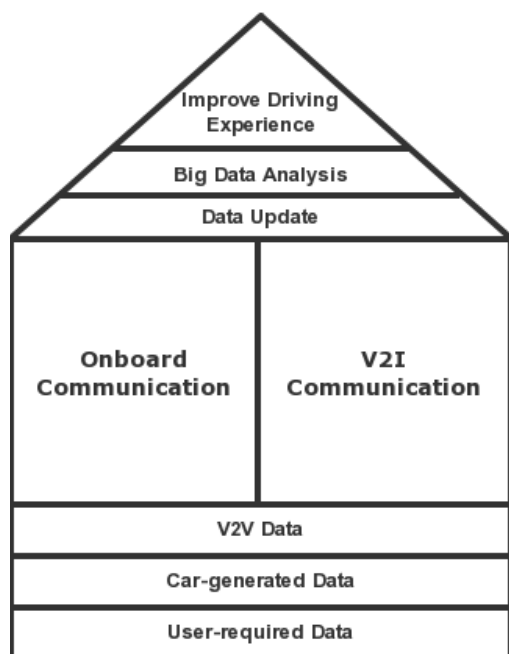


01

TECHNOLOGY OVERVIEW

In order to make better utilization of data from Toyota vehicles, we propose a hybrid network system for fast, reliable, and ubiquitous data transmission that takes advantage of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) data for real-time applications and for further analysis and feedback. This network will allow for improvements in the user experience and safety while on-board any Toyota vehicle.

Our proposed network will support V2V communication data transmission, car-generated data transmission, and user-required data transmission. We have utilized cutting-edge technologies such as Dedicated Short Range



Communications, next generation Wi-Fi, Long-Term Evolution (LTE), and Thunderbolt and Bluetooth4.0. Together, these network technologies will present Toyota an opportunity to build seamless information transmission eco-systems connecting the inside and outside worlds of a Toyota user. There are two main communication systems in our network proposal that make this possible: onboard and V2I communications systems.

Technologies in use are listed as following:

Wi-Fi

Wi-Fi is a local area wireless computer networking technology based on IEEE 802.11 standards, which allows electronic devices to network. The development of Wi-Fi technology and massive expansion of its use has allowed for easy, accessible and convenient access to the internet in hotspots and at the home. Wi-Fi networks may be established by business to attract customers, created in public spaces for anyone to use freely, or set up for household use.



Bluetooth

Bluetooth is a wireless technology standard, based on IEEE 802.15.1, for exchanging data over short distances from fixed and mobile devices, and building personal area networks (PANs). Bluetooth technology is by far at the front of the technological train, which has changed the way we talk to people on phones in the vehicle. The revolutionary Bluetooth 4.2 achieves low-power IP connectivity, industry-standard encryption, 2.5X faster with a huge packet capacity, could be the best solution to connect all the technology in the vehicle.





Long-term Evolution(LTE)

LTE is a natural technology evolution for most global system for mobile (GSM) operators. It is a step from third-generation (3G) to eventual fourth-generation (4G) wireless technology. It will become the dominant wireless broadband standard. On maturity, it could match the speed of wired (fiber) broadband in some regions, and enable a wide range of "in the cloud" services to be delivered wirelessly.

Dedicated Short Range Communications(DSRC)

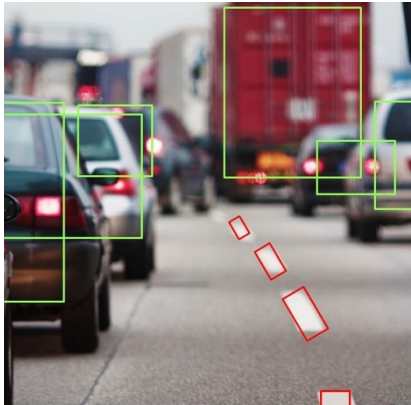


DSRC are one-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards based on 802.11p. It is A vehicular communication networks which complies with DSRC standards supports both vehicular on-board units (OBU) and roadside units (RSU).

Computer Vision



Object recognition (also called object classification) – one or several pre-specified or learned objects or object classes can be recognized, usually together with their 2D positions in the image or 3D poses in the scene. This technology has been very developed used for many applications, Google Goggles provides a stand-alone program that illustrate this function. It is an image recognition mobile app developed by Google. It is used for searches based on pictures taken by handheld devices. For example, taking a picture of a famous landmark searches for information about it, or taking a picture of a product's barcode searches for information on the product.



Text recognition

Optical character recognition (OCR) is the mechanical or electronic conversion of images of typed, handwritten or printed text into machine-encoded text. It is widely used as a form of data entry from printed paper data records, whether passport documents, invoices, bank statements, computerized receipts, business cards, mail, printouts of static-data, or any suitable documentation. It is a common method of digitizing printed texts so that it can be electronically edited, searched, stored more compactly, displayed on-line, and used in machine processes such as machine translation, text-to-speech, key data and text mining. OCR is a field of research in pattern recognition, artificial intelligence and computer vision.¹

¹ See the reference



02

APPLICATION RECOMMENDATION

Personal Comfort

Introduction

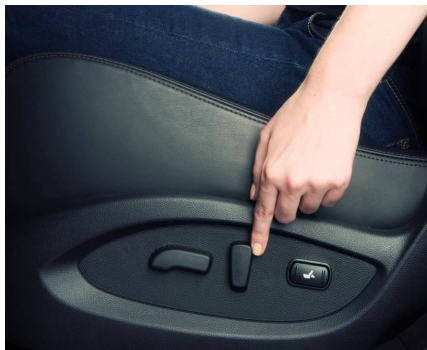
Comfort is expected of any Toyota vehicle; it is a distinguishing feature that attracts and retains customers. ebConsultants want to preserve this attribute, while also innovating and bringing additional value to the Toyota user. We believe the Personal Comfort application achieves both



goals. At its core, this application aims to personalize comfort to each Toyota user and then allows them take that comfort to any Toyota vehicle.

Comfort is the manner in which a car is set up that allows the driver the best possible experience. We believe the following factors are critical in offering the most comfortable in car experience:

- Position of side and rear view mirrors
- Position of seat and seat height
- Position of neck pad
- Height of steering wheel



As it is currently set up, the driver has to adjust these settings manually every time they enter a new car or after someone else enters their car. This process is time consuming and labor intensive. The Personal Comfort application will revolutionize the way Toyota drivers adjust their car and will bring predictive intelligence to Toyota cars. There is no such smart adjustment features among any car manufacturers, so we believe the application of Personal Comfort in Toyota vehicles will set Toyota apart from its competition and will attract customers looking to buy “smart” vehicles.

Benefits

The benefits of our Personal Comfort application can be categorized in three classifications: safety, convenience, and personalization. In terms of safety, we believe our application will avoid potential dangerous accidents due to the lack of properly adjusting mirrors, seats, and steering wheel. Many drivers have no clear idea on the correct position of these things and generally neglect the time it takes to adjust these



Low back pain affects about eight out of 10 people at some point in their lives. The smoothness of the ride and specific vehicle features, such as lumbar support and seat adjustability, can make or break your back comfort, experts say.

settings². With our application, Toyota cars come packaged with the proper and safe settings for the driver. This can reduce the frequency of accidents in the future. Moreover, the negligence of not properly adjusting settings can lead to chronic back pain³ for the driver and place their personal health in jeopardy. The Personal Comfort application prevents these sorts of things and ensures the driver is safe at all times.

Personal Comfort also benefits drivers because of the convenience it provides. With all the manual adjustment a current driver is expected to do, it takes well over a few minutes to get the car on the road. Personal Comfort will diminish this time to a few seconds and will provide the driver an instant adjustment of car settings to their preference.

Lastly, Personal Comfort provides the ability of personalization to each user of a car. It is common for a car to be used by more than one driver and currently new drivers have to manually adjust the car to their liking. However, with Personal Comfort, drivers can simply turn on the car, log in, and let the application take care of everything else instantly and in any Toyota car.

Application:

Personal Comfort is divided into two parts: the verification and the data transfer. The verification is based on a unique username and password authentication that is given to a driver at the time of their car purchase. When the driver enters the car, the car entertainment system turns on and prompts the driver to enter their Toyota login information.

² <http://www.cheatsheet.com/automobiles/americans-are-not-adjusting-their-car-mirrors-properly.html/?a=viewall>

³ <http://www.edmunds.com/car-buying/car-features-for-drivers-with-back-pain.html>

Drivers are given the option to save their information (after the initial login) in order to save time. Additionally, if the car is within a Wi-Fi range, drivers can open their Toyota Entune application on their mobile device and login via the application. In the case that a guest is driving the vehicle, Personal Comfort allows the guest to login via their social network (i.e.: Facebook, WhatsApp or Apple ID). Their settings are then saved in the cars internal storage unit and when the same guest enters the car in the future and uses their social network login information, the car is easily able to retrieve the information and adjust the car instantly.

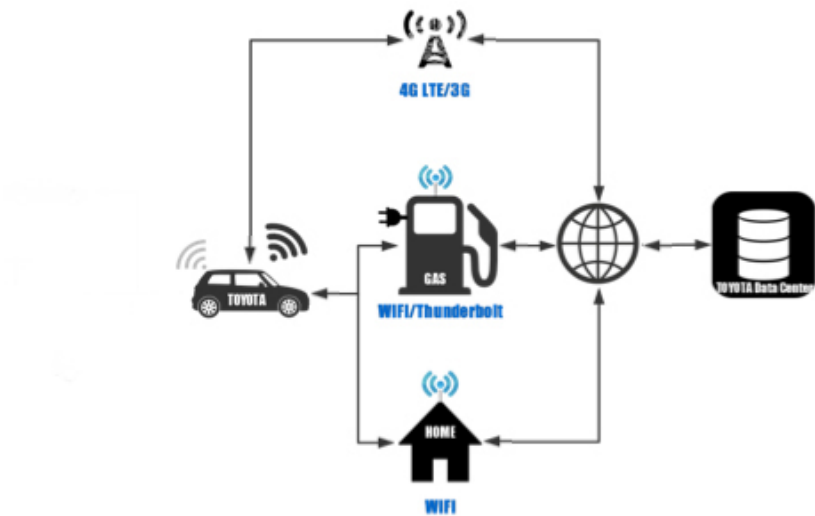
Data transfer occurs at a few stages in the verification process. After the initial set up, the data is pushed to the Toyota cloud database center and the data is paired with the driver's unique Toyota account. Simultaneously, this data is also stored onboard the vehicle. The storage of the data in the vehicle allows for faster data retrieval speeds as the data is more easily accessible for the internal processors of the car. Once the verification is approved, the mechanical systems of the Toyota vehicle access this stored data and adjust the angles, positions, and heights of the mirrors and seats as predefined by the driver. When the process is complete, a notification in the entertainment system confirms the settings and allows the driver to put the car in reverse or drive mode.

Implementation:

The data is not that big since it is only about the angles, the positions of the seat, mirrors or others. Its size is ranging from 10KB to 100KB, thus the speed and the bandwidth is not that much important since its size is too small. Moreover, it is not time-sensitive, since it is only about the settings within

the car. And the latency is much important considering the user's experience, because if the user has to wait so long time, he or she may get upset.

There are two ways of implementation our Personal Comfort system. The first one is via the cellular network. The second one is via Wi-Fi.



Dependable Care

Introduction:



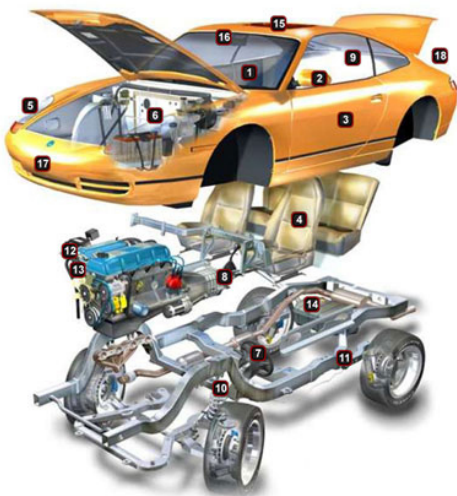
Maintenance of a vehicle is a critical part to any car driver's experience. With proper maintenance, the driver is rest assured of the safety and durability of their vehicle. Toyota stands as the leading car manufacturer in this domain. Toyota vehicles are trusted for their dependability. We want to safeguard this perception and therefore propose the Dependable Care application. Dependable Care makes the maintenance of cars easier and more accessible to drivers, while reducing costs to Toyota.

Currently when there is a maintenance issue, the driver has to take their Toyota vehicle to their closest dealership and have it inspected. This is generally inconvenient for the driver and is a labor-intensive process. With Dependable Care, the need to regularly visit a dealership is eliminated. Dependable Care makes it possible for the driver to have their car inspected and checked for proper maintenance at a push of a single button. Dependable Care utilizes the current onboard sensors of the car and transmits this sensor data to a nearby Toyota data center to have it examined by professional mechanics. The maintenance analysis produced by these professionals is sent back to the car and the driver is given an immediate report detailing the status of their car. This allows drivers to be made aware of current issues with their car and prevent future ones.

Benefits:

There are three major benefits that come with Dependable Care: utilization of untapped data, real-time maintenance reports, and model specific analytics for Toyota manufacturers. Toyota cars are complex machines that are equipped with all kinds of sensors, detectors, and embedded software. Such that, there are approximately 30 to 50 engine control units in a car⁴. This means that there is a lot of generated data. However, currently, there is no intentional use of this data to improve the Toyota experience for the driver. With our application, this untapped data can be utilized to provide value to the Toyota customer.

Real-time maintenance reports is a value creating benefit of Dependable Care because it reduces the time and labor



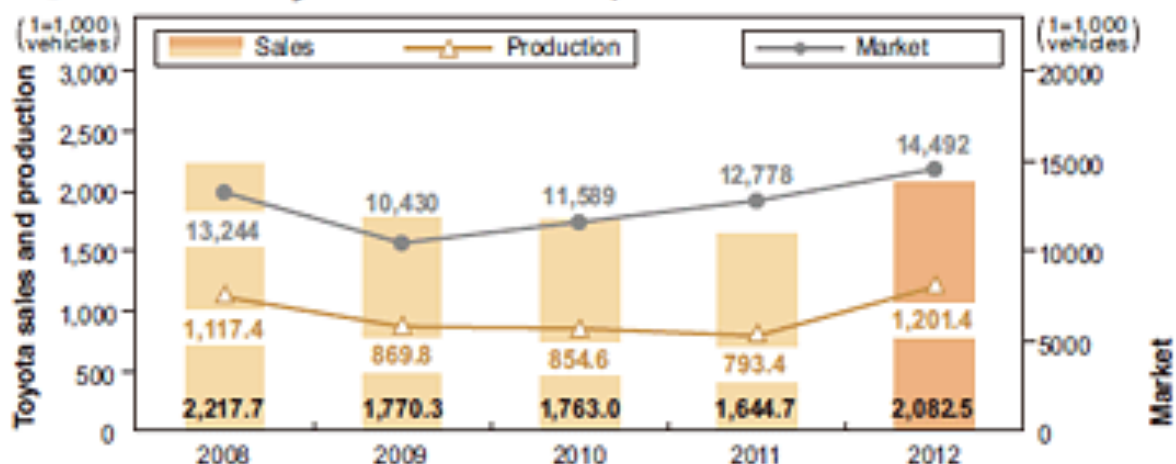
4 <http://spectrum.ieee.org/transportation/systems/this-car-runs-on-code>

involved in keeping a car properly running. Currently, the Toyota driver has to take their car to the dealership for even a simple software update. Dependable Care can eliminate this problem and make maintaining a car easier and more streamlined than it is currently. Since the application collects data from all points in a car, it can send this data to a professional car mechanic instantly for them to inspect the problem remotely. Once they diagnose the car, the car mechanic can simply send the information back to the user. The benefits to the driver in this process is that it is fast, not labor intensive, and they get to know about the status of the car at anytime and place they wish.

Lastly, with Dependable Care, value is created to Toyota car manufacturers because advanced analytics can be provided from the data collected that allow Toyota to identify major problems in their models before a recall has to occur. From 2009 to 2010, Toyota recalled more than 9 million cars and trucks worldwide due to several vehicles experiencing unintended acceleration. In 2012, Toyota recalled 7.43 million vehicles to fix malfunctioning power window switches. In early 2014, Toyota recalled more than 7 million vehicles

U.S.A

Market/Toyota sales and production



due to airbag problems⁵. The recalls reduced Toyota's sales as well as reputations. With Dependable Care, Toyota can diagnose major problems early on and issue software updates or proceed with proper steps without having to recall their vehicles.

Application:

Dependable Care works by collecting data from the sensors onboard a car, temporarily storing it in the car in order to compress the data size, and then transmitting the data to the Toyota cloud data center via a home Wi-Fi or a gas station Wi-Fi network system. At the cloud data center, this data is easily accessed by a professional Toyota specialist who can inspect the report and check for inconsistencies and send his findings back to the driver. The report comes in the form of an email or a notification to the drivers' mobile device.

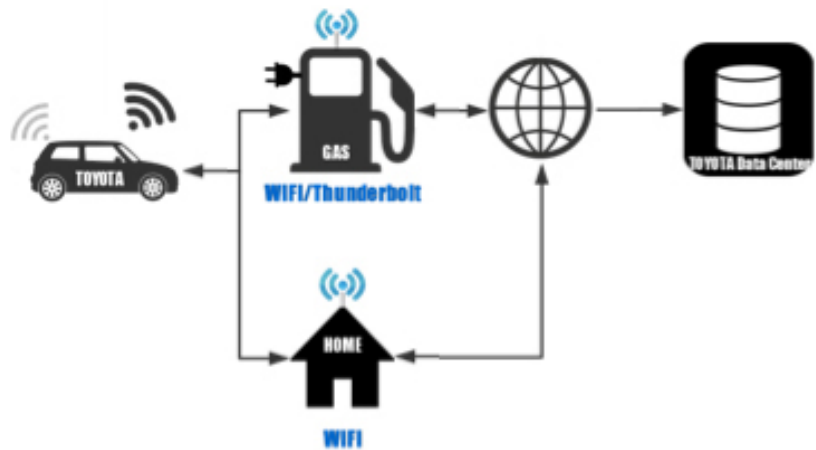
Implementation:

The data is in large amount, and is not time sensitive, since the data gradually accumulates along the time. Suppose one has his tank filled up twice a month, the data is transmitted twice a month. According to IBM big data papers, car sensors produce 1.3GB data per hour⁶. And we use compress technology to resize it to 200MB. Suppose one drives 4 hours a day, then total data produced in one day is $200\text{GB} \times 4 = 800\text{MB}$. Suppose one has his Toyota car fill up twice a month, then the data that is transmitted to Toyota data center is $800 \times 15 = 12\text{ GB}$. And we use 802.11ac Wi-Fi technology which can provide as much as 7Gbps, thus the

⁵ <https://en.wikipedia.org/wiki/Toyota#Recalls>

⁶ <http://www.ibmbigdatahub.com/blog/big-data-wheels>

transmission can be finished within several minutes in gas station.



Update on the Air

Introduction:



The dramatic increase in the amount of software in cars is creating a rapid change in the automotive industry that will bring more connectivity to the driver's finger tips and offer new ways for car manufacturers to increase user satisfaction, while at the same time saving money. Today, a software update is used mainly for in-vehicle infotainment systems (IVIs) and map content. However, moving forward, with the advancements being made in automotive software management, these software updates will soon be able to update all models of a vehicle in its entirety – from bumper to bumper – with one reliable and efficient software update campaign. The efficient management of this software allows car manufacturers to quickly respond to recall problems and

decrease overall costs ⁷. With this in mind, we are recommending the Update on the Air application. This application automates updates that are critical to the functioning of a car and limits the hassle of the driver going to a dealership for simple software patches.

Benefits:

There are two core benefits for the Update on the Air: convenience and preventive care. The service of Update on the Air aims to realize “over the air” software updates, which do not require owners to bring their cars to the dealer for a scheduled update or go through the hassle of an unplanned visit. To the driver, we present the Update on the Air as an application that allows cars to “fix themselves”.

Update on the Air also helps Toyota deal with concerns of recall. Recently, over 370,00 Toyota cars were recalled because they were at risk for overheating. However, Toyota later confirmed that this problem could have easily been avoided with a dealer-installed software patch, had it known about it earlier⁸. Update on the Air allows for Toyota to identify these problems before hand (with the use of Dependable Care) and push instant software updates to problematic models without putting burden on the driver or losing money and reputation recalling cars. In short, Update on the Air benefits customers and Toyota by improving customer relations.

⁷<http://www.redbend.com/data/upl/whitepapers/Cost%20Effective%20Updating%20of%20Software%20in%20Cars%20Whitepaper.pdf>, page 4

⁸ http://www.greencarreports.com/news/1099146_recall-2012-2014-toyota-prius-v-software-update-to-cure-stalling

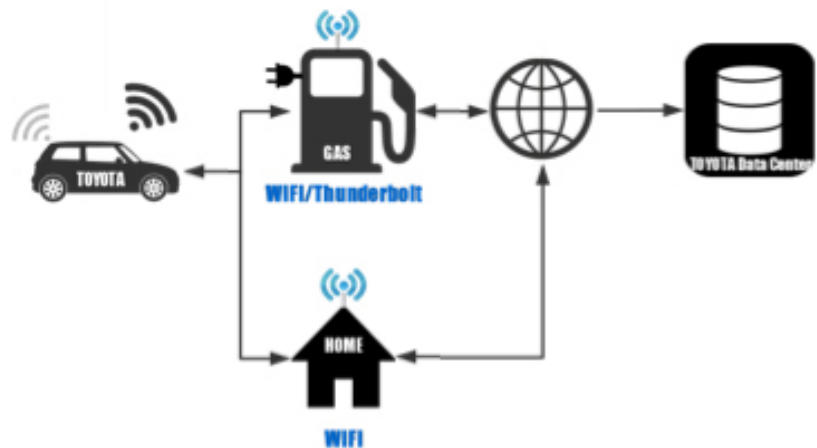
Application:

Update on the Air works by matching the Vehicle Identification Number of a particular Toyota car with the required software or firmware updated. The update is created as a package at the Toyota data center and is temporarily stored in the cloud. Once an update is deemed necessary, a notification is pushed to the driver's smartphone letting them know of the update, the issues it fixes, and the size of the update. The user can then use their home Wi-Fi network to download and install the update on their car, even if it is turned off, or choose to go to a near by gas station to install data intensive updates.



Implementation:

Typical data volume of a single software update is at 1 GB level, and the embedded software package size is now tens of megabytes for engine and transmission controllers, while audio/infotainment systems are usually the largest and most complicated software units, often exceeding 100MB. The data is transmitted by 802.11ac Wi-Fi.



My Entune

Introduction:

The relationship between consumer electronics and automotive entertainment systems is intensifying as the amount of data utilized by the user becomes a factor in the development strategies of automotive manufacturers. 64% of users store some percentage of their music and video on their mobile devices⁹. A typical user's music library consists of 7,160 songs¹⁰ and assuming an average .mp3 audio file is about 8 MB¹¹, the typical user has about 25 GB of audio. Coupling this with a typical user's video collection, the average size for a user's music and video collection is about 40-50 GBs of data. Current mobile devices simply do not offer the users the luxury to have all their music and video libraries with them.

⁹ <http://www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/>

¹⁰ <http://9to5mac.com/2011/01/04/a-look-at-the-average-itunes-library/>

¹¹ 320 kilobytes per second * 60 seconds * 4 minutes (average song length) = 76800Kbs = 8 megabytes



This is why we recommend the My Entune application to our Toyota customers. This application will allow Toyota customers to take their entire music and video library with them wherever they go and have access to these files instantly. In turn, this will allow for a better user experience for Toyota car owners and will further attract customers who view entertainment as a primary feature in their decision to purchase cars.

Benefits:

The primary benefits of the My Entune application are ease of use and streamlined entertainment. Currently, drivers also have access to their music and video, but use different services to access these media files. For example, streaming audio services such as Pandora and Spotify, or stand-alone music software such as iTunes, force the user to operate each application separately while in the car. However, My Entune can streamline this and make all these different applications “speak to each other” and offer a clean interface of the all the user’s music and video library in one place for instant and easy access. This also improves safety while driving because the drivers are not distracted by operating their phones to switch between different apps. Instead, things such as pause, skip, and save music can all be done at the push of a button on the steering wheel. We believe My Entune will offer value to Toyota car owners who want the best in-car entertainment possible.

Application:

Similar to other applications we have recommended, the basis of the My Entune lies with the unique Toyota id drivers are prompted to create at the purchase of their new car.



Once at home, the user can log into their Toyota account online and start the link their music and video accounts to their Toyota account. My Entune supports the following music and video services: Spotify, Pandora, iTunes Music, Amazon Music, Amazon Video, and Netflix. By simple logging in once and linking their accounts to the Toyota ID, users can access their files stored on these devices on their car directly. This is made possible because we will have engineered stock applications in the car memory unit that runs these applications. In essence, the user is linking their account from one application platform to another.

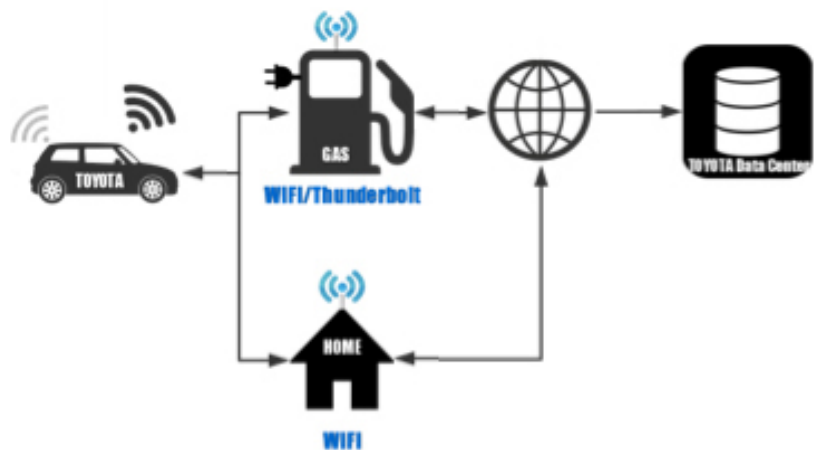
At the same time, users are allowed to upload their personal music and video collection stored on their computers. We will have a dedicated 1TB worth of storage in the car and the user can allocate how much ever space of this they prefer to store their additional music and video. They can store the files in the internal storage unit in two ways: Wi-Fi or cloud services. Depending on the file size, the user can choose to use their home Wi-Fi network to upload these files to the car. In the case that users do not wish to do this, they can use our gas station network speeds to instantly upload their chosen files the next time they fill their tanks. The user can also store their personal music and video collection in a cloud storage service of their choice (Google drive, Amazon drive, or iCloud). The cost here is null to Toyota because these cloud services are priced according to individual plans so the user has control over how much data they wish to store in the cloud. Then once again using their personal Wi-Fi or the gas station wireless networks, they can upload these files to their car for quick and direct access.

This application also works in the manner that it builds pattern-recognizing algorithms to observe what kinds of

music a user likes. After generating a pattern, a user can set up notifications that Toyota pushes of new songs and artists that the user might like based on their previous uploads to the car. This offers a personal touch to our application and distinguishes it from any other application available in the market right now.

Implementation:

The data from My Entune is transmitted via WI-FI from home and gas station. Assuming a user uses the maximum 1TB of data, 802.11ac can transfer 7GBs of data per second .1000 Gb/ 7Gbs is roughly 145 seconds or close to 2 minutes. Therefore, the max time it takes to transfer data is 2 minutes. The frequency that this data is exchanged is at the discretion of the user.





Intelligent Travel

Introduction:

Intelligent Travel will allow drivers to be more informed when they travel to unfamiliar places. Currently, drivers use their smartphone applications to look up places or points of interest when they are visiting places. There are three major problems with this. First, the user has to access multiple applications in order to find something of interest. Second, the current available travel aid applications expect the user to have a predefined idea of what they are looking for and do not offer personalization or recommendations based on past usage behavior. And lastly, it is simply unsafe to be accessing these applications while driving. We believe Intelligent Travel will address and fix all of these problems. In short, Intelligent Travel will streamline all travel related information and present this information in a interactive and visually pleasing manner that helps augment the Toyota driving experience. This type of application is simply not available in other cars and we believe it will set Toyota apart from the competition.

Benefits:

The main benefits of this application are the ease of use and personalization. Rather than forcing the driver to use multiple applications, Intelligent Travel will integrate the various applications findings into one interactive list. This will offer a seamless driving experience for the user. Moreover, Intelligent Travel offers personalization that is simply not

available in other cars. As the user uses the application frequently, Intelligent Travel can learn the types of places the user is more likely to go to and can use this pattern recognition to filter recommendations and display places or points of interest tailor made for the driver.

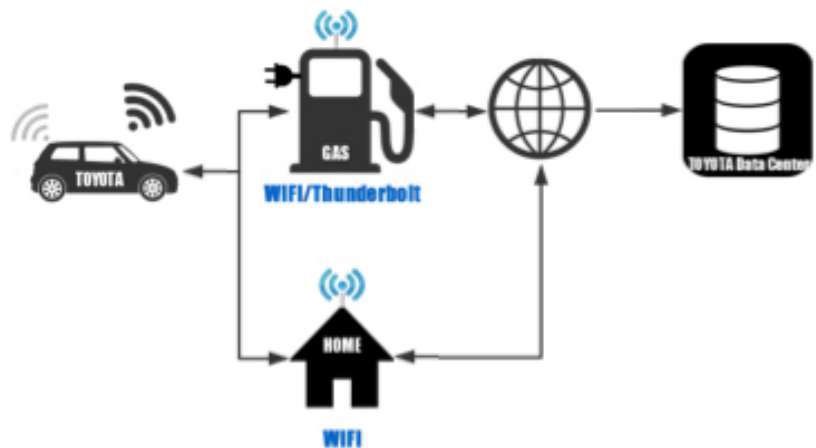


Application:

Once again, the Toyota id forms the basis of our application. Upon receiving their unique id, users can log onto Toyota online where they can set up the Intelligent Travel application. They can link the following accounts to their Toyota id: Facebook, Twitter, Instagram, Yelp, Expedia, Travelocity, and Orbitz accounts. Once this information is linked, they users can confirm letting our Toyota data center know that they have linked all necessary accounts. Upon confirmation of this, the data center parses the following information from the applications: places visited (so the application can recommend future places of interest), restaurants visited (so the application can recommend future restaurants and also the types of cuisines the user has a preference for), hotels stayed at (so the application can recommend future places) and it extracts reviews from Yelp for the above suggestions and uses their Facebook, Twitter, and Instagram accounts to notify the user if a friend of theirs in these social network had visited any of the recommended places. This parsed information is sent to the Toyota vehicle either using the personal home Wi-Fi of the user or at a gas station depending of the size of the file.

Implementation:

When the user goes to the gas station, they can download this data to their car's entrainment unit using 802.11ac. Since the data we are accessing from the sources is not raw data and is in the form of packets and "compressed" data (done at the data center) the file sizes should be small around 100 MB level.



Efficient Gas

Introduction:

Gas efficiency is an important criterion for many customers when buying a car. Customers equate gas efficiency to saving money¹²; therefore, it is important that Toyota markets

¹² <http://www.thesimpledollar.com/how-important-is-fuel-efficiency-when-purchasing-a-car/>

their vehicles as being able to help customers save money. Along with gas efficiency is the issue of gas prices. In fact, choosing the right gas station can save a user 15% or more¹³. However, this can be very hard. The price of gas could be different between adjacent gas stations or even gas stations from the same petroleum company can have different prices within the same area. Therefore, in properly filling gas there are two main factors: knowing when to fill your car and knowing where to fill your car at the best price. The Efficient Gas application solves both problems. At its core, Efficient Gas functions in the following three ways: it generates accurate real-time reminders to let users know of gas refills, it provides real-time prices of gas at gas stations nearby the user, and it offers accurate navigation to these stations.

Benefits:

The three main benefits of Efficient Gas are: effective notifications, efficient gas pricing information and time conservation. Efficient Gas application provides effective notification to remind you of refueling. 67% of cell owners find themselves checking their phone for messages, alerts, or calls — even when they don't notice their phone ringing or vibrating.¹⁴ Compared to reading gasoline level from dashboard, notification on users' phone is better reminder. Because many people forget the warning of low gas level when they leave their cars but remember to check their phone often, we can push notifications to the users phone reminding of to fill their gas before it reaches to levels that pose an obstacle to the operation of the vehicle.

¹³ <http://money.stackexchange.com/questions/13856/why-do-gas-stations-charge-different-amounts-in-the-same-local-area>

¹⁴ <http://www.pewinternet.org/fact-sheets/mobile-technology-fact-sheet/>

Efficient Gas also benefits the user by allowing them to save money on gas. Currently, an average household spends about \$250 per month on motor gas fuel¹⁵. Moreover, many users wait until the last possible moment to refill their gas. However, research has shown those who fill gas at the last possible moment spend more than those who fill at the first sign¹⁶. We believe by providing smart advice as to when to fill gas and where to do it at, users can utilize the information to save money.

Lastly, Efficient Gas will save time for the user by accurately guiding them to the gas station of their preference. This feature is useful when drivers find themselves in unfamiliar areas. Rather than depending on an external application and toggling between applications checking for gas prices and locations, Efficient Gas provides all the necessary information as well as accurate directions in a simple interface that integrates all critical components.

This application will be a really good marketing strategy for Toyota since there are no other similar notification systems implemented in other car manufactures. Customers will be more willing to buy or rent Toyota cars. Currently, there are some websites as well as mobile applications providing the nearest cheapest gas station information¹⁷, such as gasbuddy¹⁸, gas guru¹⁹. But compared Efficient Gas, these applications are isolated with the car, and the driver has to open the app while he is in the car, which poses a safety hazard. Simply put, Efficient Gas will create value for the user in all respects.

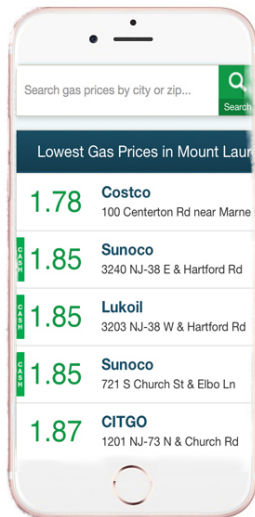
15 <https://gma.yahoo.com/how-much-do-americans-spend-on-gas-each-month-.html>

16 <http://www.consumerreports.org/cro/news/2011/05/running-on-empty-low-gas-in-the-tank-can-be-costly/index.htm>

17 for those who put off the fuel stop until the last possible moment, the costs could be even higher.

18 <https://play.google.com/store/apps/details?id=gbis.gbandroid>

19 <https://play.google.com/store/apps/details?id=com.yellowpages.android.gas>



Application:

It is first important to know how current gas notifications work in order to understand how Efficient Gas separates itself from the competition. A fuel gauge (or gas gauge) is an instrument used to indicate the level of fuel contained in a tank²⁰. As used in vehicles, the gauge consists of two parts: the sensing unit and the indicator. The sensing unit usually uses a float connected to a potentiometer, typically printed ink design in a modern automobile. As the tank empties, the float drops and slides a moving contact along the resistor, increasing its resistance. In addition, when the resistance is at a certain point, it will also turn on a "low fuel" light on dashboards. This is the level of information a regular car currently provides.

Efficient Gas is different in that we connect a sensor to the above system and push the data generated to the Toyota cloud data center. When the volume of gas reaches a level that needs the driver's attention, the Toyota cloud system will receive this information. The cloud system will then generate data of different gas prices and distance of gas stations according to the car's location. Then, it will analyze the data at filter out unfavorable gas prices and far gas stations. After the cloud system does this analysis, the integrated information will be sent to the users' phones as a notification. This notification includes multiple plans to different gas stations with shortest distance and cheapest gas price. The plans also include accurate navigation to gas stations. This application can save users' home address and work address to provide plans for users when they get off work and start a ride from home.

²⁰ https://en.wikipedia.org/wiki/Fuel_gauge

Implementation:

When the volume of gasoline reaches the level that the driver needs to be notified, there will be data sent to Toyota cloud system, the size of the data will be really small, probably hundreds of KB, which only includes the location of the car and the car needs to be refueled. The notification data Toyota send back to car users will also be small, around 2MB, which includes the information of navigation to gas stations and gas prices. All the data is transmitted via LTE.



Smart Tip

Introduction:

According to a recent market research, at least 20% of drivers say they have never used more than half of the tech. features in their cars²¹. Moreover, a survey by J.D. Powers

²¹ <http://www.cnet.com/news/many-people-dont-bother-using-in-car-technology-survey-says/>



concluded “automakers spend billions on technologies that many consumers do not use²²”. It is imperative that when car manufacturers invest so many resources in providing a better experience to the driver, the driver should be equipped with the knowledge to use the technology. Smart Tip provides exactly this type of knowledge. It is composed of two parts: instructions about in-car functions drivers may not know about and recommendations about using certain functions based on driver behavior. These tips are personalized to each user of a car and will revolutionize the way drivers use their Toyota cars.

Benefits:

The obvious benefit of Smart Tip is that it will help car users make more use of their in-car technologies and features. It is a good way for drivers, especially those new to driving, to learn how to operate their car and the functions the car provides. This type of knowledge is currently expected to come from reading a dense car manual. But that is cumbersome on the user. With Smart Tip, a simple notification to the driver’s phone will allow them to learn what they need to know instantly and intuitively.

Another benefit of this application is the added safety awareness. By letting users know how to use their car and what function each feature serves, the user is better prepared to use their car safely and properly when facing a dangerous situation. Smart Tip acts as a preventive care in this respect.

Lastly, Smart Tip can provide valuable analytics to Toyota for research studies as to how drivers use their vehicles. This

²² <http://www.pnwswire.com/news-releases/automakers-spending-billions-on-technologies-that-many-consumers-dont-use-300132473.html>

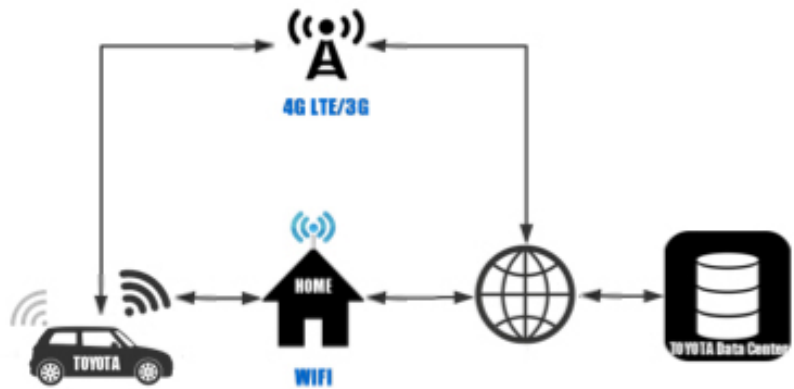
user study would be useful for Toyota in order for them to improve their cars' human interactive design. For example, based on the data it receives from Smart Tip, Toyota can recognize the behavior of users while using a certain feature and may think about changing it to improve its functionality or removing it if it hinders a driver's experience. Simply put, Smart Tip provides data that can be harnessed to develop future Toyota in car technologies.

Application:

Smart Tip generates data from sensors to get information of the usage of in-car functions and analyze drivers' behaviors. The sensors are used in two ways: internally and externally. Internally, we implement sensors that are able to record how often and for how long a certain button or feature in the car is being used for. For example, this may include things such as how often the brakes are used and how often the driver uses their all wheel drive. The external sensors record things of the external environment such as temperature or fog levels. Then, this data is compressed as packets (not raw data) and pushed to the Toyota cloud data center, via a home Wi-Fi network or our gas station network proposal, in order to analyze the data. The internal and external data reports are analyzed to see observe things such as a pattern recognition between the two reports and among each individual report. Once the analysis is complete, the report is sent as an email to the user's Toyota id and a notification is pushed to the user's mobile device letting know of things they can do to improve their future driving experience.

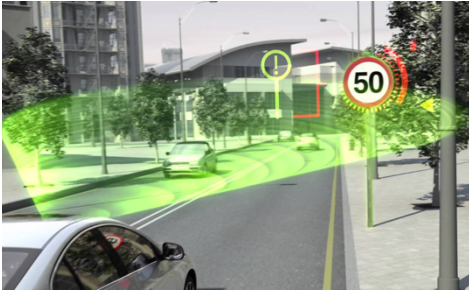
Implementation:

The data of this application generated in the car won't be large, it could be transmitted to the gas station which may be once or twice in a week. Daily data collected in car is around 2MB. The data won't be complex operating data for every function in the car. And the feedback can send to users through home Wi-Fi. The size of feedback data depends on the recommendation given to drivers, usually less than 10MB.



Smart Eye

Introduction:



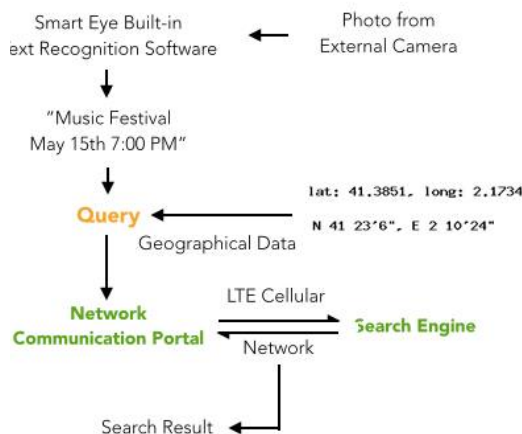
The most innovative application we have developed is the Smart Eye application. The core function of the application is to bring artificial intelligence to cars in order to understand the external environment instantly and bring real-time analysis and information of this information to the user. Some of the technology required to implement such an application is already present in cars. For example, current car systems utilize external radars to detect the presence of moving objects, lasers to measure distance for cruise control, and video and ultrasonic technologies to detect objects behind or around the driver. Moreover, breakthrough in artificial intelligence technologies allow for the possibility of Smart Eye. Developments in the computer vision field allow for various applications that enable computer software to acquire, process, analyze and understand images with data input from the real world in order to produce numerical or symbolic information. In essence, we want to bring technologies that are currently isolated into one system that employs them to perform a novel operation. In the case of the Smart Eye, this operation is to sense and understand the outside world and provide valuable information to the user based on this understanding.

Benefits:

Smart Eye offers two important benefits: improvement of user experience and innovation of artificial intelligence in cars. User experience improves with Smart Eye because the user becomes more aware of the environment they are in and are

informed about the types of things available in the area. However, we believe Smart Eye is an application that holds most of its benefit for what it can offer in the future for Toyota users. With the current breakthroughs in technologies and artificial intelligence, a minimal recognition and understanding is possible. But, the future looks promising. We want Toyota users at the forefront of the next technical revolution in cars, artificial intelligence. By providing the basis for the future technologies, we believe value is added to the user because of the “future-proofing” the car offers. Toyota users can be rest assured that Smart Eye will not go obsolete in the near future and can easily be updated to accommodate the developments as they occur in the future.

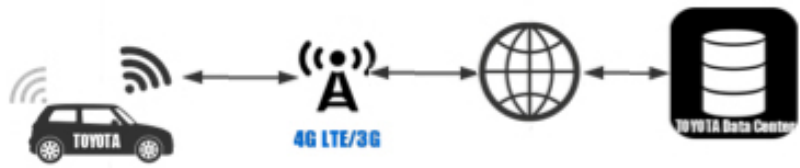
Application:



Smart Eye is a mixture of hardware and software improvements, with software improvements being more important. We will install external cameras and sensors to future Toyota cars that can capture images and other information from the external environment. But the more important aspect of our application in use is the software update we will be providing to Toyota cars installed with these sensors. Using computer vision, we will be able to process the data generated from these cameras and sensors internally and use the software to analyze the data and provide valuable information about what the external environment holds. It is critical to understand the value of Smart Eye will be realized in the near future and we believe Toyota should be ready for it.

Implementation:

The network used for Smart Eye service is cellular network for real time data interaction between the car and the internet and Toyota data center. The transmitted data volume is up to 10 megabytes/hour during the trip.



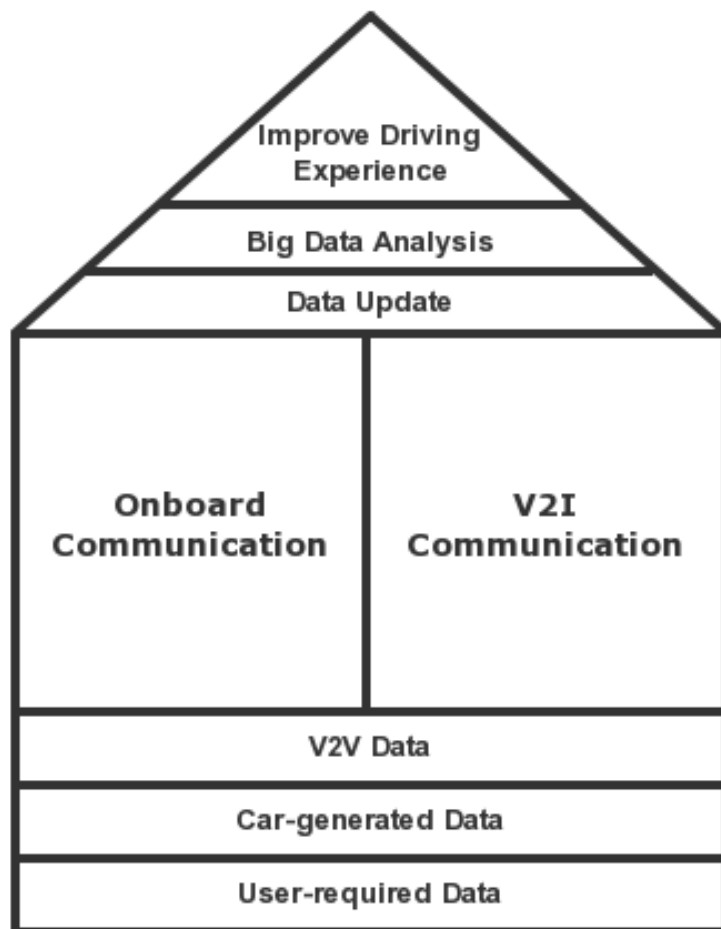


Introduction

In order to realize our applications, we propose a hybrid network system for fast, reliable, and ubiquitous data transmission that takes advantage of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) data for real-time applications and for further analysis and feedback. Moreover, this network will allow for improvements in the user experience and safety while on-board any Toyota vehicle. Our network will provide:

- Compatibility for heterogeneous data
- Fast data transmission
- Real-time communication
- Exclusive steady data connection
- Cost-effective implementation and installation

Using the above capabilities, our proposed network will support V2V communication data transmission, car-generated data transmission, and user-required data transmission. We have utilized cutting-edge technologies such as Dedicated Short Range Communications, next generation Wi-Fi, Long-Term Evolution (LTE), and Thunderbolt and Bluetooth4.0. Together, these network



technologies will present Toyota an opportunity to build seamless information transmission eco-systems connecting the inside and outside worlds of a Toyota user. There are two main communication systems in our network proposal that make this possible: onboard and V2I communications systems.

Onboard Communication System

Overview

The onboard communication system turns every Toyota car into a network hub. Beyond currently available onboard infotainment systems, our proposed system will link personal portable devices, ECU, auxiliary view systems and Wi-Fi hotspots together and offer unprecedented convenience and rich data transmission and analysis to Toyota users and engineers.



Bluetooth

Bluetooth is a wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices, and building personal area networks (PANs)²³. The Bluetooth is capable of connecting to several devices simultaneously without interference between these devices. We will be using Bluetooth 4.2 for our network in cars to improve Toyota's customer experience. It includes *Classic Bluetooth*, *Bluetooth high speed* and *Bluetooth low energy* protocols. Bluetooth high

²³ <https://en.wikipedia.org/wiki/Bluetooth>

speed is based on Wi-Fi, and Classic Bluetooth consists of legacy Bluetooth protocols.

Features

The key features of Bluetooth technology are that it consumes low power, the cost of deployment is also low and it is a ubiquitous technology. The major improvement over the older personal area networks is that Bluetooth solves the problem of synchronization.

The Bluetooth Specification defines a uniform structure for a wide range of devices to connect and communicate with each other. The frequency allocated for Bluetooth to operate is from 2.4 to 2.485 GHz using a spread spectrum, frequency hopping, full-duplex signal at the rate of 1600 hops/sec.²⁴

Additionally, Adaptive frequency hopping (AFH) was developed as a part of Bluetooth technology to reduce interference between wireless technologies sharing the 2.4 GHz spectrum. AFH works within the spectrum to take advantage of the available frequency. This is done by the technology detecting other devices in the spectrum and avoiding the frequencies they are using. This adaptive hopping among 79 frequencies at 1 MHz intervals gives a high degree of interference immunity and also allows for more efficient transmission within the spectrum. For users of Bluetooth technology this Adaptive frequency hopping provides faster and reliable performance even when other technologies are being used along with Bluetooth technology. Bluetooth has already been implemented in

Toyota car stereo systems (Entune™) but our design integrates the new Bluetooth 4.2 to the system with increased data transfer speeds and lower battery

²⁴ <http://www.bluetooth.com/Pages/Basics.aspx>

consumption in mobile devices. The following table shows the rate of data transfer according to the evolution of Bluetooth technology:

Attainability



Entune (the in-car infotainment system in Toyota cars) integrates Bluetooth into its system to enable the Toyota customer to make hands-free voice calls and streaming music from mobile devices, among other things, through the system. Bluetooth technology has become a very common feature used for connecting mobile devices in cars. We will be using the new Bluetooth 4.2, which introduces some key features for IoT. Some features, such as Data Length Extension, require a hardware update. But some older Bluetooth hardware may receive Bluetooth v4.2 features, such as privacy updates via firmware. Since Bluetooth

Version ²⁵	Data rate	Max. Application throughput
1.2	1 Mbit/s	>80 Kbit/s
2.0 + EDR	3 Mbit/s	>80 Kbit/s
3.0 + HS	24 Mbit/s	>3 Mbit/s
4.0	24 Mbit/s	>4 Mbit/s

technology has been implemented, it has been improving and we recommend Toyota to introduce the advanced Bluetooth technology to refine the customer experience. Bluetooth is technology widely utilized but we believe the potential for further advancements is possible with Bluetooth 4.2 The major areas of improvement in using Bluetooth 4.2 are:

- LE Data Packet Length Extension

²⁵ <https://en.wikipedia.org/wiki/Bluetooth>

- LE Secure Connections
- Link Layer Privacy
- Link Layer Extender Scanner Filter Policies
- IP connectivity for Bluetooth Smart devices to become available soon after the introduction of BT v4.2 via the new Internet Protocol Support Profile (IPSP)
- IPSP adds an IPv6 connection option for Bluetooth Smart, to support connected home and other IoT implementations



Wi-Fi Hotspots

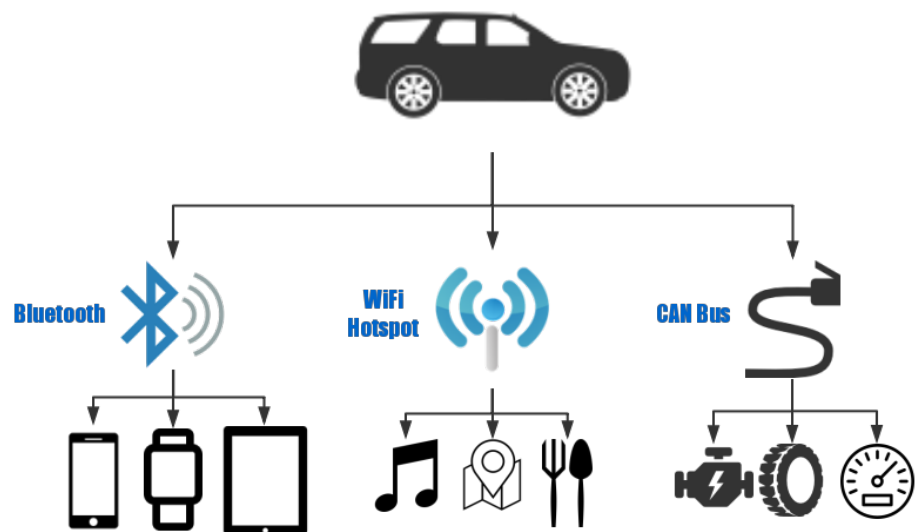
The web of connectivity of the world is getting more complex with every passing second at an exponential rate. The customers now use internet connectivity with almost all the devices they use, from smartphones to laptops to tablets to everything in between, the ability for users to get onto the Internet is the most significant and essential for them. Using the Internet wirelessly has become an elemental facet of many people's lives in this century. Therefore, we are introducing Wi-Fi hotspots to all Toyota cars.

Any wireless router placed in a Toyota car uses the provided 4G LTE connection to create a Wi-Fi hotspot. This will allow users to perform intensive tasks on the go. Instead of using a Mi-Fi wireless router for Wi-Fi hotspots, we recommend Toyota use in-car 4G LTE connections that can effectively turn the car into a big moving mobile hotspot. By doing this, passengers can take advantage of a WPA2-secured (or "password protected") Wi-Fi connection that can be used by everyone in the vehicle simultaneously and will allow for

multiple users to experience the benefits of a “connected” car.

System Design

At a glance, the onboard communication system is composed of three modules which are controlled by the central communication unit: Bluetooth module, Wi-Fi Hotspot, and an On-Board Diagnostic module. These three modules work together to create the on-board communication system. The features of these modules are as follows:



1. Bluetooth module allows for the following features:
 - Hand-Free Calling
 - Access to Phonebook
 - Music Stream
2. Wi-Fi Hotspot will turn the car into a mobile hotspot that will allow for fast and reliable wireless Internet access for devices onboard the vehicle.

3. On-Board Diagnostics module provides access to the data generated from Engine Control Units and offers valuable source of information to Toyota when they analyze and troubleshoot problems inside a vehicle.

Vehicle-to-Infrastructure Communication

Overview

The V2I communication system provides a hybrid network solution for Toyota cars to talk with the world. This innovative communication system has the ability to choose network data pathways dynamically. For example, the V2I communication system can choose either 802.11p supported Wi-Fi transmitter network for regular data exchange, the LTE networks for real-time data transmission, or the specially designed Nozzle-Plug network (powered by Thunderbolt technology) to transfer large data in a matter of seconds. This sort of dynamic network enables rapid data exchange between vehicles and the Toyota Data Center. Currently, vehicles are isolated “data islands” with billions of bytes of data being wasted. However, with our proposed V2I solutions, all the data generated from cars or users can be documented, recorded, analyzed, and improved to make possible a wide array of applications that improves the user experience of Toyota vehicles.





Long-Term Evolution

Introduction

Long-Term Evolution (LTE), commonly marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements.²⁶ The mobile devices use this comprehensive connectivity solution, 4G networks, to deliver voice data and multimedia content at any time and place. 4G technology standards offer greatly improved data rates over previous generations of wireless technology. Faster wireless broadband connections enable wireless carriers to support higher-level data services, including business applications, streamed audio and video, video conferencing, video telephony, mobile TV, and gaming. This high-speed data network also increases the efficiency and reduces the time used to send over-the-air updates to the vehicle or other service messages even while the car is in motion (i.e. real-time).

Features

LTE technology offers a number of distinct advantages over other wireless technologies. These advantages include increased performance attributes, such as high peak data rates and low latency, and greater efficiencies in using the wireless spectrum. Improved performance and increased spectral efficiency will allow wireless carriers using LTE as their 4G technology to offer higher quality services and

²⁶ [https://en.wikipedia.org/wiki/LTE_\(telecommunication\)](https://en.wikipedia.org/wiki/LTE_(telecommunication))

products for their customers. The benefits expected from LTE technology are as follows²⁷:

- High peak speeds:
 - 100 Mbps downlink (20 MHz, 2x2 MIMO)—both indoors and outdoors.
 - 50 Mbps uplink (20 MHz, 1x2)
- At least 200 active voice users in every 5 MHz (i.e., can support up to 200 active phone calls).
- Low latency:
 - < 5ms user plane latency for small IP packets (user equipment to radio access network [RAN] edge).
 - < 100ms camped to active.
 - < 50ms dormant to active.
- Scalable bandwidth:
 - The 4G channel offers four times more bandwidth than current 3G systems. The 4G technology is also more flexible and adaptable than 3G networks. So, while 20 MHz channels may not be available everywhere, 4G systems will offer channel sizes down to 5 MHz, with spacing of 1.5 MHz in the bandwidth to reduce interference.
- Improved spectrum efficiency:
 - Spectrum efficiency relates to how limited bandwidth is used by the access layer of a wireless network. The 4G network uses the improved spectrum efficiency to access more data from the network while increasing the

²⁷ <http://innovation.verizon.com/content/dam/vic/PDF/LTE%20The%20Future%20of%20Mobile%20Broadband%20Technology.pdf>

- number of users and services the network can support.
- From the HSPA (Release 6) benchmark, the speed have increased about two to four times.
- Improved cellular data rates:
 - The 4G network also increases the cellular coverage area, also know as cell edge.
 - Over the previous benchmark, (HSPA Release 6) the data rates are also increased by two to four times.

Attainability

However, the crux of the attainability is how to improve the network connectivity while accommodating for the increased data consumption rates by users. On the 2015 model-year vehicles equipped with 4G, GM is offering the service free for three months or 3 gigabytes of use. Following the free trial period, plans start at \$5 a month for OnStar subscribers and \$10 a month for non-subscribers for 200 megabytes. The current plans top out at \$50 a month for 5 gigabytes of data use. A 4G LTE-equipped Toyota vehicle also can be added to an existing AT&T Mobile Share Plan for \$10 a month.²⁸

Two-hundred megabytes of data, according to AT&T's usage calculator, is enough to stream more than 6.5 hours of music, surf the internet for 13 hours or send more than 10,000 emails without attachments.

There are a lot of other technologies that have been implemented in cars for internet connectivity such as Satellite Wi-Fi and GPS. However, we do not recommend the satellite

²⁸ <http://www.techhive.com/article/2154720/gm-announces-pricing-for-its-4g-lte-service-to-debut-in-2015-chevrolet-malibu.html>

Wi-Fi (Sat-Fi) because it may be good for voice calling, SMS texting and small emails but it is not good for internet connectivity, which is our main purpose. These Sat-Fi²⁹ offer a very low speed of 9 Kilobits per second connection. Even if we use broadband internet through Sat-Fi we get a speed of 250 Kbps, which is very low and inefficient compared to data rates of 100Mbps in 4G LTE networks.



Wi-Fi

Introduction

As Wi-Fi technology evolves at an exponential pace, we must understand available Wi-Fi standards in order to make the best business decisions when recommending new wireless gateways to Toyota (i.e. performance versus cost). We will be using the most recent advancement of wireless networks to 802.11ac. We will also discuss the advancement of MIMO antenna technology from 1x1, 2x2, 3x3 and even 4x4 which drastically reduces the length of antenna used. Therefore, we suggest that the 802.11ac wireless communication should be used in the gas stations where the data from our applications (which have high bandwidth requirement) will be transferred. This transfer will not only include the data from our applications but, also the data from the Engine Control Unit of the car which contains all the data about the car required by Toyota.

Features

The 802.11ac is the main wireless network we are adopting in the gas station for Toyota cars while they are being fueled or charged. This Wi-Fi communication happens only between car and gas station whereas we will use optical fiber

²⁹ <http://globalnews.ca/news/1610689/sat-fi-your-personal-satellite-connected-wifi-hotspot/>

connection from the gas station to the central Toyotas servers via the internet service providers. 802.11ac achieves its drastic improvements in speed by pushing on three different dimensions:

- Greater channel bonding, increased from the maximum of 40 MHz in 802.11n, and now up to 80 or even 160 MHz (for 117% or 333% speed-ups, respectively).
- Denser modulation, now using 256 quadrature amplitude modulation (QAM), up from 802.11n's 64QAM (for a 33% speed burst at shorter, yet still usable, ranges).
- more multiple input, multiple output (MIMO). Whereas 802.11n stopped at four spatial streams, 802.11ac goes all the way to eight (for another 100% speed-up).³⁰

Therefore, the data rates we have seen lie in the theoretical range of eight 160MHz 256-QAM channels, each of which are capable of 866.7Mbps — a grand total of 6,933Mbps, or just shy of 7Gbps. That's a transfer rate of 900 megabytes per second more than the speeds of the SATA 3 connections. Though, the maximum practical speed (or throughput) for 802.11ac achieved is around 3.9Gbps for 5GHz frequency.

Attainability

802.11ac is a faster and more scalable version of 802.11n. 802.11ac integrates both the freedom of wireless networks and the high speeds of Gigabit Ethernet. 802.11ac not only increases data rates but also increases number of customers

³⁰ http://euro.econ.cmu.edu/resources/elibrary/auto/5th_gen_Wi-Fi.pdf

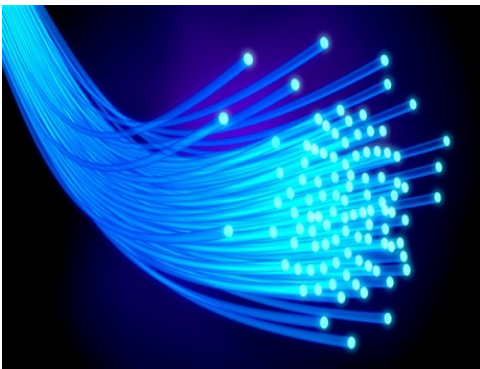
that can connect by an access point without sacrificing the speeds, which would result in a better experience for each client, and more available bandwidth for a higher number of parallel video streams. Even when the network is not fully loaded, users see a benefit: their file downloads and email sync happen at low-lag gigabit speeds. The time for 802.11ac is indeed now, with the ever-increasing demands of increased data rates, reduced lag, improvement in number of connections.

Optic Fibers:

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Due to much lower attenuation and interference, optical fiber has large advantage over existing copper wire in long-distance and high-demand applications³¹. To transfer data collected by the gas stations back to the Toyota data center, we take advantage of the existing fiber optic network deployed by some major ISPs.

The optical cables are considered a reliable method of connection because the FiOS is a passive system, which means even during blackouts, a fiber optic network has very low probability to crash.

The FiOS has extraordinarily fast speeds and can send data over very long distances. The Fiber-optic internet offers download speeds in the range of 150Mbps and 500Mbps and upload speeds from 70Mbps to 100Mbps. The data that we have calculated goes to a gas station from the Toyota cars is around 5Gb per day. The size of this data can be

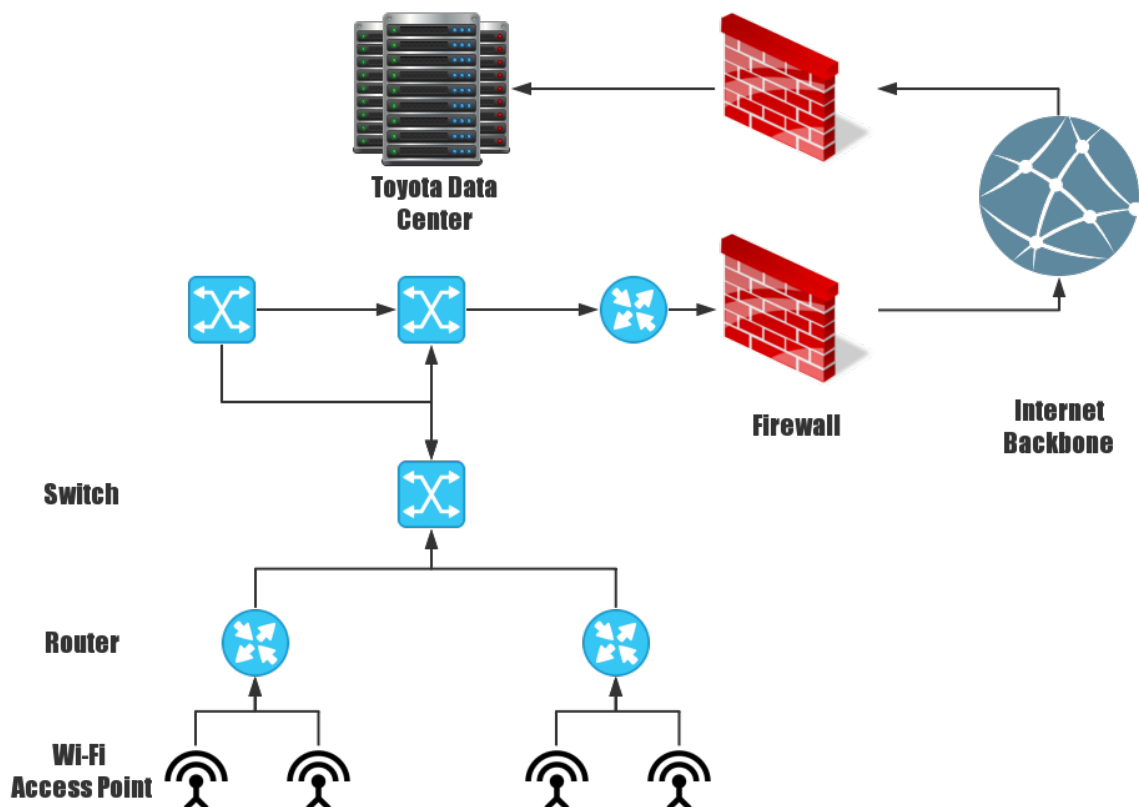


³¹ https://en.wikipedia.org/wiki/Fiber-optic_communication

easily handled by the high data rates of the Fiber-optic network. The cost to install and maintain the fiber optic is around \$500 and then \$300 per month which is only a minimal cost for Toyota to implement in the affiliated gas stations.

The optical fiber system can be generalized by two parts:

- At the gas station end, access points allocated around gas station are connected to the terminal router. Different routers from the same gas company link together via switches, and finally linked to the central routers, which connect to the internet backbone through firewall.
- At the data center end, data from the backbone Internet will first filtered by firewall and finally access



to the Toyota data center through enterprise-level firewall.

System Design

The Vehicle-to-Infrastructure system is a hybrid network involving vehicle-end and infrastructure-end implementation. On the vehicle-end, cars are equipped with a 802.11p and 802.11ac supported Wi-Fi transmitter and a 4G LTE modem. Since Wi-Fi is widely used in both V2V and V2I communications, our onboard Wi-Fi modules will integrate both 802.11p and 802.11ac networks because each provide their own benefit:

- 802.11p: collects V2V data through the common protocol provided by Intelligent transportation system (ITS)
- 802.11ac: communicates with infrastructure end Wi-Fi at gas stations or user's home garages

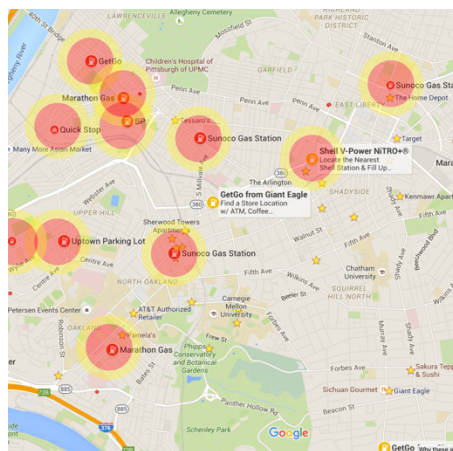
LTE Module

LTE is the real-time data transferring solution for our V2I communication system, mainly responsible for real-time small-size data update, breakpoint resume, onboard Internet request and emergency connection.

Infrastructure Wi-Fi AP

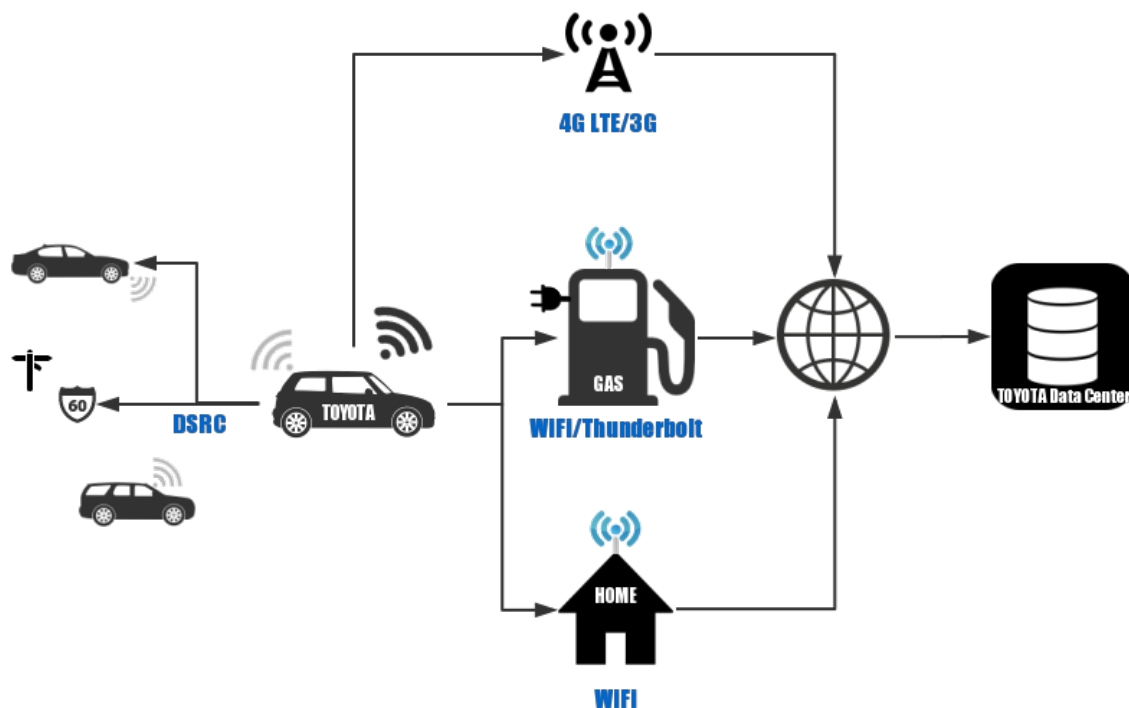
In our solution, gas station in contract with Toyota are required to install 802.11ac Wi-Fi access point to provide Internet connection for Toyota cars.

Implement details³²:



Frequency	5 GHz
Channel bandwidth	160MHz
AP power	23dBm (=200mW)
AP antenna height	2.4m
Antenna gain	3dBi
Vaild range	500m

32 A Comparative Study between 802.11p and Mobile WiMAX-based V2I Communication Networks



Features

Package Compression

Hardware Level compression

Our network requires heterogeneous data transmission, which could be slow and unstable. When data from different sources come to the central communication unit (CCU), the CCU will first examine the priority of that data based on its updating frequency. Data with similar frequency would be packaged together into a package, then stored into data cache. When a vehicle approaches the Wi-Fi AP range of a gas station, the package would be uploaded to the server through the network as a whole.

Software Level Compression

To make better use of the capacity of network, we provide a unique code-based data transfer mechanism, which means some routine communication tasks should be encoded. Raw data and the whole operating procedure should be pre-installed into the onboard memory, in this way, only code (like OBD code) rather than the entire data should be sent over our network. We also recommend third party developer follow this rule during their development. The core idea is to fully exploit the onboard storage and analyzing ability and make the data transmission as brief as possible.

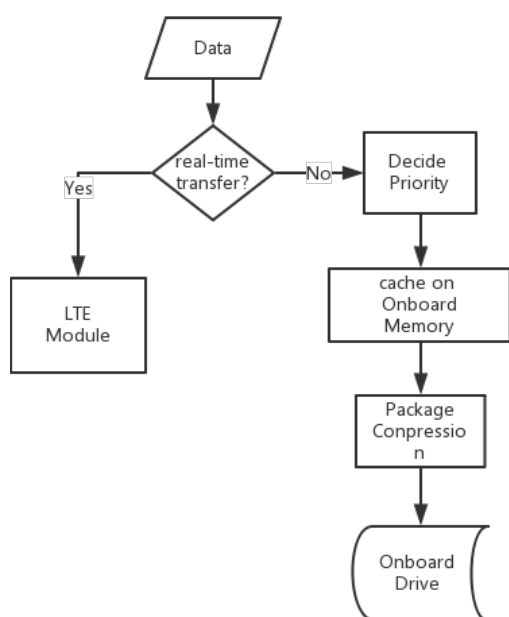
User ID	Task ID	Range	Content Length	Date
1000001	02ca57e173c11:95b	2000070-106786027	106786028	Mon, 30 Apr 2015 12:55:20 GMT

Data Cache

Car generate data could be store in onboard hard drive temporarily.

Onboard Memory: for temporally data storage waiting in queue for compressing or transmission.

Onboard Drive: for permanent storage, we provide 1 TB SSD for each car. Users could save their multimedia files, clouds backup on the car. Our network would take few GB for system operation. Packages could also be stored in the onboard drive before uploading to the online server.



Breakpoint Resume

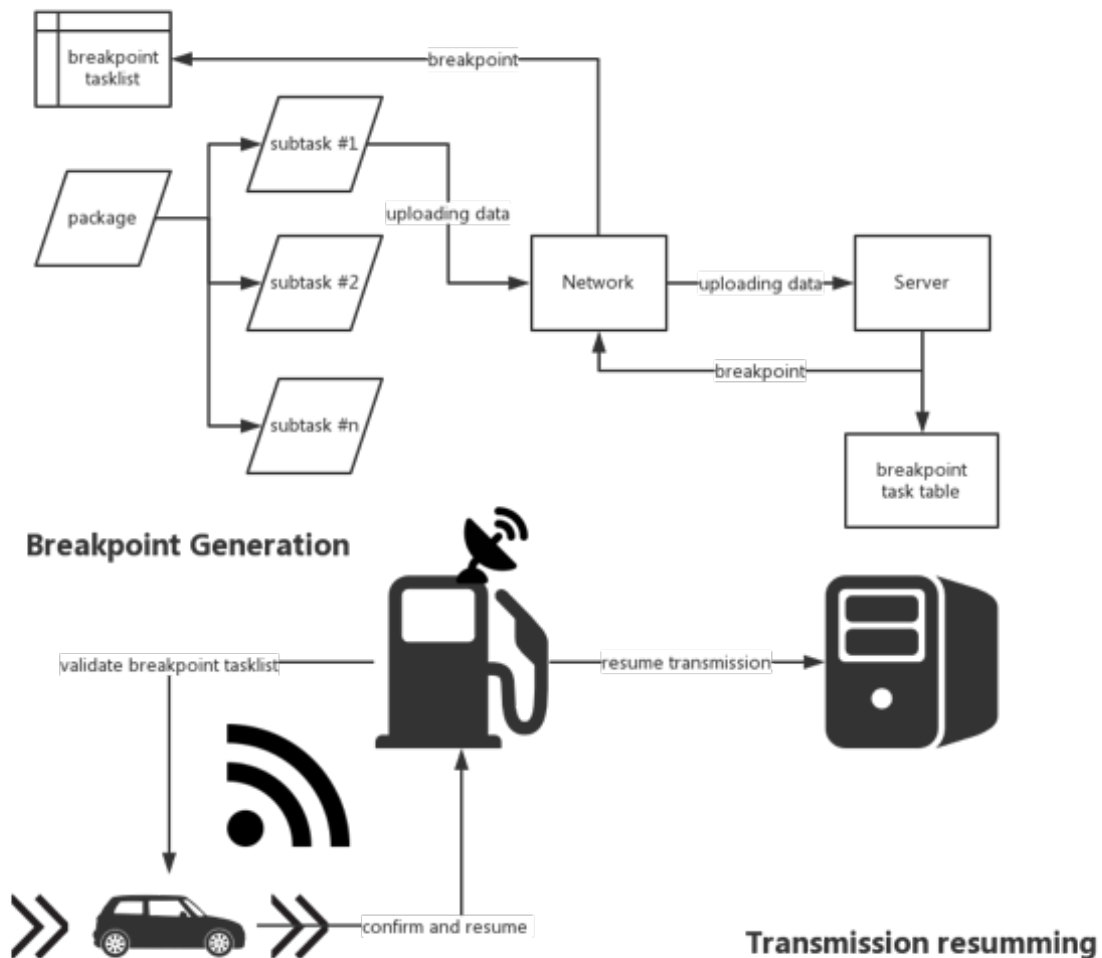
In case that the data transmission can not be finished during the limited refilling period, our network provides broken resuming mechanism to ensure the continuity of telecommunication. All data collected from vehicle should be packaged into a unified format by central communication unit. Within the header, there would be:

- user ID
- Task ID
- Range
- Content Length
- Date

Package would be divided into sub-tasks for multitasking upload, and clouds sever will keep monitoring the procedure of uploading/downloading.

When the vehicle drives out of the range of Wi-Fi coverage zone, communication break, and the server will automatically generate a breakpoint of this transmission task, save it to the database and notify the vehicle via cellar about this breakpoint.

When this vehicle drives through another gas station, vehicle will talk to the server through wifi connection again and check for break task, and thus resume data transmission without the awareness of user.





REFERENCE

1. Wi-Fi(Wikipedia): <https://en.wikipedia.org/wiki/Wi-Fi>
2. Bluetooth(Wikipedia): <https://en.wikipedia.org/wiki/Bluetooth>
3. DSRC(Wikipedia): https://en.wikipedia.org/wiki/Dedicated_short-range_communications
4. LTE(Wikipedia): [https://en.wikipedia.org/wiki/LTE_\(telecommunication\)](https://en.wikipedia.org/wiki/LTE_(telecommunication))
5. “Bluetooth 4.0: What is it, and does it matter?” <http://www.cnet.com/news/bluetooth-4-0-what-is-it-and-does-it-matter/>
6. “The Impact of WiFi on Society” Jason Von Kundra, Information Technology 103-008,October 4, 2012. <http://it103wifi.blogspot.com>
7. Outline of object recognition(Wikipedia): https://en.wikipedia.org/wiki/Outline_of_object_recognition
8. Press Releases, Bluetooth.com <http://www.bluetooth.com/Pages/Press-Releases-Detail.aspx?ItemID=220>
9. Importance of Fuel Efficiency <http://www.thesimpledollar.com/how-important-is-fuel-efficiency-when-purchasing-a-car/>
10. Mobile Technology Fact Sheet <http://www.pewinternet.org/fact-sheets/mobile-technology-fact-sheet/>
11. Gas Price Difference <http://money.stackexchange.com/questions/13856/why-do-gas-stations-charge-different-amounts-in-the-same-local-area>
12. American Spent on Gas Each Month <https://gma.yahoo.com/how-much-do-americans-spend-on-gas-each-month-.html>
13. Fuel Gauge https://en.wikipedia.org/wiki/Fuel_gauge
14. Survey about Technology Use in Car <http://www.cnet.com/news/many-people-dont-bother-using-in-car-technology-survey-says/>

15. J.D.POWER Report about In Car Technology <http://www.prnewswire.com/news-releases/automakers-spending-billions-on-technologies-that-many-consumers-dont-use-300132473.html>
16. Americans are not adjusting their car mirrors properly <http://www.cheatsheet.com/automobiles/americans-are-not-adjusting-their-car-mirrors-properly.html/?a=viewall>
17. Car Features for Drivers with Back Pain <http://www.edmunds.com/car-buying/car-features-for-drivers-with-back-pain.html>
18. This Car Runs on Code <http://spectrum.ieee.org/transportation/systems/this-car-runs-on-code>
19. Toyota Recalls <https://en.wikipedia.org/wiki/Toyota#Recalls>
20. Big data on Wheels <http://www.ibmbigdatahub.com/blog/big-data-wheels>
21. Cost Effective Updating of Software in Cars <http://www.redbend.com/data/upl/whitepapers/Cost%20Effective%20Updating%20of%20Software%20in%20Cars%20Whitepaper.pdf>
22. Recall: 2012-2014 Toyota Prius V Software Update To Cure Stalling http://www.greencarreports.com/news/1099146_recall-2012-2014-toyota-prius-v-software-update-to-cure-stalling
23. U.S. Smartphone Use in 2015 <http://www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/>
24. A look at 'the average' iTunes library <http://9to5mac.com/2011/01/04/a-look-at-the-average-itunes-library/>