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Road Traffic Management using Vehicle-to- Everything (V2X) Communication

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By

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To begin with, I would like to dedicate this thesis to my late father, who was a constant inspiration to continue my graduate studies, and to thank my mother and wife for their full support during this program at RIT.

I would also like to thank Dr. Ioannis Karamitsos and Dr. Sanjay Modak for the continuous academic support they provided me, which made this project a success.

Finally, a deep thanks to RIT Dubai for the exciting program we had to learn and experience.

Abstract

Traffic congestion is the primary concern in dense cities; while the increased number of automobiles is becoming uncontrollable in some cities, it is more challenging to manage or change how people use cars. To contribute to solving traffic congestion in cities, this project examines the study of transferring vehicles to be competent in a way that can help the government entities analyze the received vehicles' data and for better decisions on reducing traffic congestion as well as the real-time monitoring of traffic wherever it is located using the Vehicle-to-Everything (V2X) communication methodology. This study proposes a hardware "system" that can be attached to any vehicle to collect real-time data from vehicles and communicate with the Road and Transportation Authority. The hardware system, however, is connected to the cars through a wireless On-Board Diagnostics (OBD) connection in favor of collecting all the necessary information from the vehicle, such as the car speed and Revolutions Per Minute (RPM) data. On the other hand, a GPS sensor is used to inquire about the vehicle's location, a GSM module to make sure the device is always connected to the internet for data transmission, a LiDAR sensor for distance and safety measurement, and a camera module accessed only by the driver for object detection such as cars, pedestrians, traffic signs, damaged roads, and road hazards. Moreover, system updates and maintenance can be done remotely to reduce the number of visits to the traffic department since all devices are to be connected to a single platform. As a result, it was possible to create a prototype for a single vehicle, including the sensors mentioned above, returning valuable data that include vehicle speed and exact location, which will help future researchers develop an application platform to monitor and track traffic congestion in real time.

Keywords: Smart City; Vehicle to Everything (V2X); Intelligent Transport Systems; Traffic Congestion; Big Data; Smart Road Traffic Management; On-Board Diagnostics (OBD).

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1.1 Statement of the Problem

As cities are heading towards becoming smart, many issues arise during this transition. A smart city's definition does not only include the technologies used, transferring systems into related sub-systems, and the sharing of information but also considers how smart the people are while using these systems and the level of collaboration in the city. This section will discuss the problem that cities face and how this project will contribute to solving it.

In most cities, automobiles are still becoming smart, as the definition differs from city to city. All attempts of transferring vehicles into smart became either a gadget or a service provided by a third-party company. At the same time, many of them use advanced technologies which can be attached to cars that are either expensive or hard to fix, especially on old and low-priced vehicles.

However, when we think about contributing to the city by becoming smart, we must consider many other aspects, such as climate change, residents' safety and health, and big data management. Nowadays, the increase of population in cities relatively increases the use of vehicles and transportation in general; and to be able to control the massive amount of congestion carefully and the other problems transportation creates, this project will help initiate a solution to study and analyze traffic congestions in the city to provide a better picture on how to reduce congestions and how to take steps to better traffic management. In the meantime, Tesla is a good example of a smart vehicle that uses up-to-date technologies for driver's safety and many other features that benefit the smart city. In my opinion, using electric cars is undesirable for some people, and motorized vehicles will continue production for at least the next hundred years. This project presents the vehicular network as an emerging technology in the Intelligent Smart Transportation era.

The network provides mechanisms for running different applications, such as accident prevention and traffic congestion. The network will be designed using Vehicle-to-Everything

(V2X) approach. The main characteristic of V2X communication is that it enables all vehicles on the traffic road to communicate with the traffic authority to enhance traffic performance and increase road safety.

In summary, cities are heading towards digitization of their services and creating initiatives to build a better life for their citizens. This project intends to introduce to the traffic authorities and city departments the implementation of a solution for analyzing and overcoming traffic congestion, reducing accidents, and collecting and analyzing big data in the hope of contributing to reducing the negative impact of vehicles on the environment.

1.3 Background Information

A smart city is a complex system that includes sub-systems; with the internet and smart sensors, we can connect these systems to manage city tasks efficiently and quickly. Yet, while focusing on the connectivity of these systems, we must efficiently use them considering the environment and the city's residents' health. A smart city is a collection of connected departments and entities using ICT solutions to enhance how people live efficiently and sustainably.

Smart automobiles might differ in definitions. In the 1990s, cars were called smart when they included a GPS navigation system or a reverse sensor for safety. According to PCMAG (n.d.), others in the United States call smart vehicles to those designed to use less gasoline. In this project, smart automobiles refer to the simultaneous connectivity amongst all cars in a city using specific devices and technologies to monitor and manage their data in real-time.

Vehicle to Infrastructure (V2I), according to Wikipedia contributors (2021), is defined as a collection of technologies that are used to link vehicles to their surroundings and the engineering of roads to cope with the use of vehicles and to increase the safety of passengers. In this dissertation, vehicle to infrastructure is referred to the communication between vehicles and the road infrastructure, such as road signs and lanes, and identifying turns and damages in the roads. V2I is one of the components of Vehicle to Everything technology.

Vehicle to Everything (V2X) concept, according to 5G Americas (2018), refers to the communication technologies that are created for the omnidirectional vehicle-to-vehicle (V2V), vehicle to infrastructure (V2I), Vehicle to Pedestrian (V2P), and Vehicle to Network and Cloud (V2N/V2C) to modify the vehicle infrastructure as a connected system using the Internet of Things (IoT).

Global Positioning System (GPS) is a satellite-based navigation system that provides location data for sea, land, and air travel. The satellite system includes 24 satellites orbiting above the earth. In this project, a GPS module is used as a component of the vehicle device for real-time traffic monitoring.

A global System for Mobile Communication (GSM) is used in this project and refers to the use of cellular networks for communication and information transmission. In addition, this standard makes it possible for devices to be connected to the internet using different internet protocols to transmit the required data to the road and transport authorities.

1.4 Project Goals

The main focus of this project is to convert vehicles of all kinds to smart; smart means a connected system that will be able to contribute to the development of a smart city as well as the contribution to reducing environmental issues that are caused by vehicles. The goals of this project include but are not limited to the following:

- Updating the vehicle infrastructure
- Designing and implementing a low-cost vehicle agent that includes multiple sensors
- Reducing the cost of currently used technologies
- Decrease the environmental issues caused by traffic congestion
- Connecting all vehicles in a sustainable approach in addition to the monitoring of data in an efficient way
- The reduction of traffic congestion in the city
- Maintaining a time-efficient system in responding to road incidents
- Creating new jobs in the future through the need for installation and development of the system
- Visualization of data that benefits smart cities through the implementation of a road management platform

1.5 Project Definition

This project intends to implement a live tracking mechanism to monitor traffic congestion and provide traffic analysis for future road and traffic management decisions. No mobile phones or mobile applications are used in this implementation. However, the project will be divided into three main components:

1.5.1 Vehicle Agent

This part of the project consists of a microprocessor (Raspberry Pi), a GSM module for internet connectivity, GPS Module for fetching vehicle location in real-time, a camera module for object detection on roads, a LiDAR sensor to measure the distance between vehicles and pedestrians. The combination of all these sensors and modules will be connected to the microprocessor for further programming to achieve the goals of this project. Furthermore, the device will also be connected to the On-Board Diagnostic (OBD2) to retrieve more information, such as vehicle speed and other related car data, according to the standard EN15722.

1.5.2 Network Layer

The network layer acts as the middle communication between the Vehicle Agent and the backend system (road management platform). In this project, the communication is done through a GSM SIM900 module, connecting the vehicle agent through a SIM chip subscribed to an internet connection. GSM can also help identify car owners and keep the system connected whenever the engine runs. Figure 1 provides a rough idea of how the GSM Module works for wireless internet connectivity.

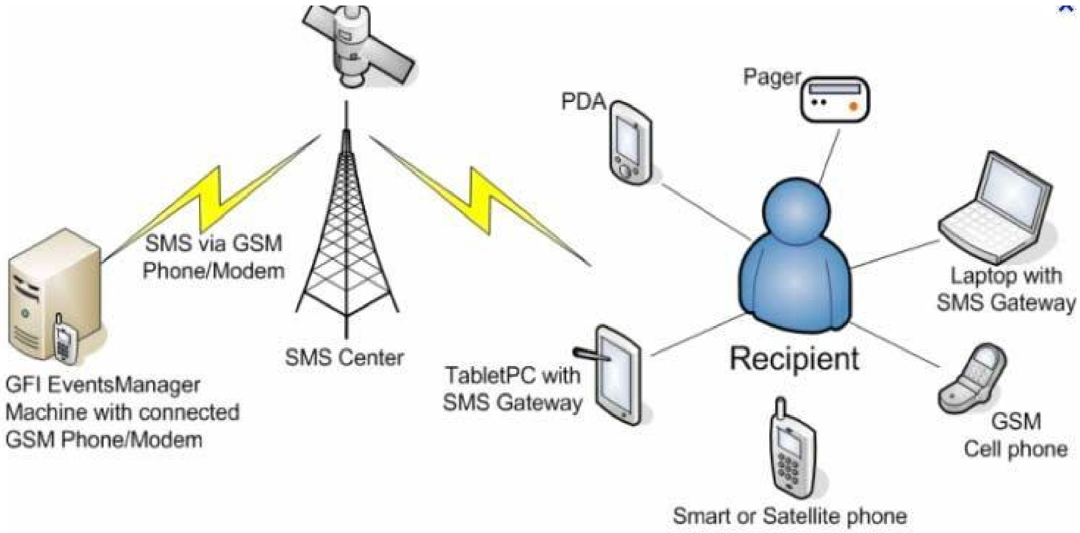

Figure 1 GSM Communication Architecture

1.5.3 Backend System – Application Service

Using database storage for this project is very important to store vehicle information and real-time data. The vehicles in the city must be distinguished using a unique identifier such as a chassis number or plate information, especially when having a massive number of automobiles; this will make it easier to identify each vehicle. The database that will be used to view the data is either neo4j or MongoDB for the efficiency of storing and presenting data. However, the monitoring system is the presentation and visualization of data received from all vehicles in the city, making it possible to view the cars in real time for analysis. Google maps API or Amazon Web Services (AWS) map services might be used for this project, but subject to change.

1.6 Project Deliverables

The deliverables of this project will include the vehicle agent devices that will be installed in all automobiles in the city; the low cost of these devices can be included in the registration renewal fees of vehicles to reduce the effects on the city budget, the maintenance of these units can be done remotely by the transport authority. Furthermore, a dedicated monitoring and road management system will be delivered to the road and transport authority for analyzing, viewing, and monitoring city traffic.

Some of the deliverables and features might be added in the future and during the project implementation (Refer to the project resources and budget estimate section for more information about the devices used throughout this project).

1.7 Project Timeline

ID		Task Mode	Task Name	Duration	Start	Finish
1			**Master's Thesis**	382 days	1/15	1/31
2			**Task 1: Vehicle Device**	**120 days**	**1/19**	**5/18**
3			Research on using the optimal devices for the Project	10 days	1/19	1/28
4			Start of Collecting Project Resources	10 days	1/29	2/7
5			Development of vehicle device	80 days	2/8	4/28
6			Task 1 Documentation	20 days	4/29	5/18
7			**Task 2: Database Selection and Development**	**60 days**	**5/19**	**7/17**
8			Select the required database for data storage	10 days	5/19	5/28
9			Database design	10 days	5/29	6/7
10			Connect the vehicle device to the database for storage	30 days	6/8	7/7
11			Testing of both Task 1 and Task 2	4 days	7/8	7/11
12			Task 2 Documentation	6 days	7/12	7/17
13			**Task 3: The development of the Vehicle Tracking Monitoring System**	**120 days**	**7/18**	**11/14**
14			Research on how to develop the system	15 days	7/18	8/1
15			Start of developing the monitoring system	70 days	8/2	10/10
16			Completing the connectivity of the tracking system to the vehicle device and database	15 days	10/11	10/25

Project: Proposal Gantt Chart - Date: 12/3

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone
Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only
External Tasks | External Milestone | Deadline | Progress | Manual Progress

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ID		Task Mode	Task Name	Duration	Start	Finish
17			Testing of all 3 Tasks	15 days	10/26	11/9
18			Task 3 Documentation	5 days	11/10	11/14
19			**Task 4: Finalizing Project Documentation**	**78 days**	11/15	**1/31**
20			Documentation editing and proofing	46 days	11/15	12/30
21			Thesis documentation and implementation completion	32 days	12/31	1/31

Project: Proposal Gantt Chart - Date: 12/3

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone
Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only
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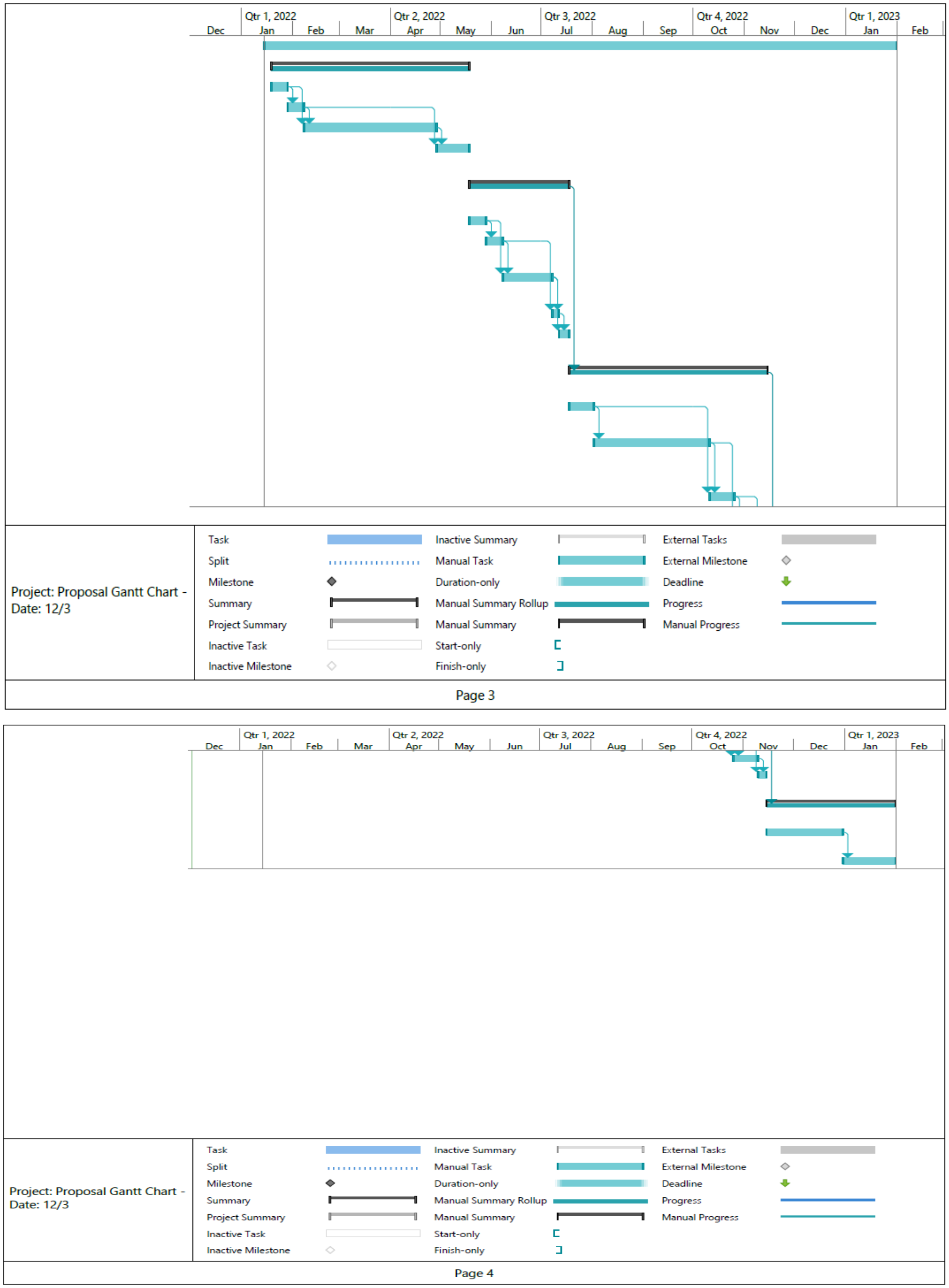

Figure 2 Gantt Chart (Project Timeline)

1.8 Project Resources and Budget Estimate

1. Raspberry Pi 3 Model B+ 1 GB RAM. Estimate price: 100 – 150 AED

Figure 3 Raspberry Pi 3 Model B

2. Ublox NEO-6M GPS Module with Antenna. Price: 150 AED

Figure 4 NEO-6M GPS Module

3. GSM SIM900A. Price: 145 AED

Figure 5 GSM SIM900A Module

4. TFMini Plus Lidar Sensor. Estimate price: 250 AED

Figure 6 Ultrasonic HC-SR04 Sensor

5. Camera Module for Raspberry Pi – 5MP. Estimate price: 20 – 40 AED

Figure 7 5MP Camera Module

6. OBD Interface Bluetooth Sensor. Price: 23 AED

Figure 8 OBD2 Bluetooth Sensor

Chapter 2: Literature Review

Vehicle-to-everything (V2X) technologies have shown a significant contribution to the creation of a safer driving environment and enhancing the efficiency of traffic. Connecting vehicles to everything will also help reduce fatal accidents and pollution rates. A detailed testing survey conducted by Jian Wang et al. (2019) describes the different technologies V2X uses, such as the types of communications for V2X, which can be divided into two technologies, a Dedicated Short-Range Communication (DSRC) and a Long-Term Evolution for Vehicle to Everything (LTE-V2X). The DSRC uses the physical layer and the medium access control layer for data transmission among neighboring vehicles and pedestrians. However, the LTE-V2X rapidly exchanges information between vehicles, such as location, speed, and driving directions. The author also describes the importance of taking measures while implementing these systems through testing methods, considering the network delays and other obstacles and the security vulnerabilities that threaten the system. The low-cost V2X traffic lights and vehicle communication solution proposed by Konstantinos Skoufas et al. (2019) was developed to believe that vehicle routing and vehicular networks may reduce traffic congestion and CO2 emissions. The authors have designed a system containing two wireless vehicle-to-everything (V2X) devices and a central server. These connected devices can collect data from vehicles and road conditions to make decisions on selecting the optimal route with the additional use of air quality data to reduce pollution. However, the developed system focuses on developing a low-cost traffic light that is connected wirelessly to the internet and the passing vehicles, providing information about the infrastructure of the road from the counting of passing through cars to the detection of environmental changes. Yuhang Zhao et al. (2014) conducted a performance evaluation study on IEEE 802.11p communication for Vehicle to Infrastructure (V2I) using Off-the-Shelf IEEE 802.11a hardware. In this study, the authors discussed the differences between the two standards of 802.11p and 802.11a, which can be summoned that the use of 802.11a is cheaper and its functions can be altered to serve the same as the 802.11p function.

Field tests have been done to evaluate the performance of 802.11p to verify the variety of distances between vehicles and antennas, antenna heights, environmental changes, and vehicles' speeds. In summary, findings include that increasing the distance between cars and antennas creates a delay to the connection, and packet losses are always as low as 0 due to the distance. The cases of obstacles such as trees and buildings can contribute to the reliability of connectivity which meets the requirements for Vehicular Ad-hoc Networks (VANETs). Moreover, the study of vehicle-to-infrastructure (V2I) communications for safety and mobility done by Dhaya Kanthavel et al. (2021) discusses the technologies and applications required for implementing the vehicle to infrastructure; such systems require wireless communication and data sharing between vehicles using software, hardware, and a firmware. However, the study describes the wireless technologies used in V2I, including Bluetooth, Wi-Fi, Mobile Networks, and short-range radio, that help with the functionality of these systems; figure 9 shows the architecture of V2I as described by the study.

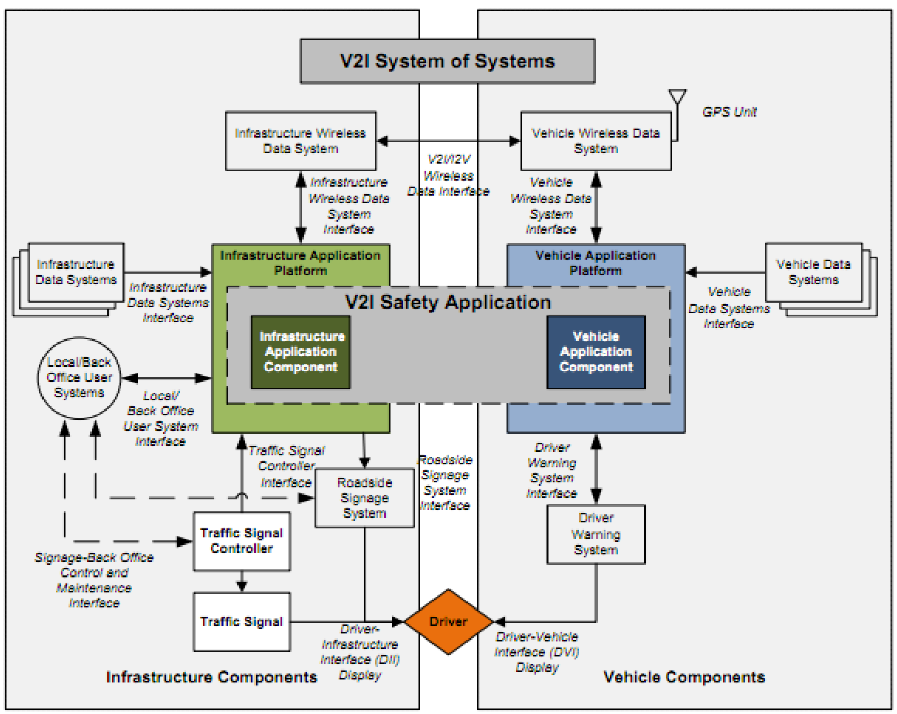

Figure 9 V2I Architecture

According to Sumit Dukare et al. (2015), vehicle tracking and monitoring are challenging due to tracking vehicle locations under specific conditions. For example, the Global Positioning System (GPS) is sometimes unreliable under weather conditions or if passing through a long tunnel. However, the Global System for Mobile Communication (GSM) alerts and sends information to the desired party for tracking vehicles. A computer vision system proposed by Benjamin Coifman et al. (1998) is an excellent example of managing traffic tracking through video surveillance and image processing technique. The system can identify the traffic density and when the vehicles enter or exit the road, providing accurate information on the movement and tracking of the traffic. Figure 10 shows a simple example of a computer vision system. As mentioned before in the project goals, using cameras and image processing is costly if installed on every street in the city. That said, the proposed computer vision system can be only used on major roads rather than all streets. Furthermore, the system was mainly created to solve the problem of vibrating cameras due to weather conditions by tracking the feature of the automobiles, such as wheels, instead of detecting the whole part of the vehicle.

Figure 10 Tracking Vehicles by a Group of Features

In the GPS-based analysis study done by Priyanka Bhosale et al. (2017), an Android application is used to notify drivers about upcoming traffic congestion to avoid it. The system uses only a mobile application to calculate the speed of a vehicle and the exact location and decide whether there is traffic. All city drivers must install the application to get the desired data or service to implement this system successfully. By doing that, many issues arise that can make the system unreliable such as the unavailability of internet connection on some of the drivers' phones, the desire of some drivers to not install the application, the use of non-smartphones, and many more. A GPS Based Automatic Vehicle Location, which is focused on Bus Transit and presented by Akande Oluwatobi (n.d), is a system that is divided into three parts as it's required for any tracking system. 1. A *computer location display system*, which is an essential part of the system to present the desired information (vehicles on map). 2*. location identification element,* called In-Vehicle-Unit, is the device that allocates the location of vehicles and the gathering of required information from cars. 3. *a communication component*. To make the transfer and reception of data which is the main idea of the system. Moreover, the proposed system uses different technologies that can make the system operatable for transport management centers for observation and traffic data collection. This system is very similar to the idea of this project. Still, it lacks the implementation and real-life data for further study and focuses only on bus transit and passenger time performance. Similarly, P.SWAPNA (2016) developed a system for people with disabilities to track and retrieve data on buses location using two-way voice communication to request the required bus information. The system has three main units, the bus unit, the bus stop unit, and the person unit. However, the person with a disability sends a request to the bus stop unit using voice commands with a Bluetooth connection. Then the request is sent to the GPS-GSM-based unit in the bus, retrieving the bus location and information to be sent to the passenger. Such a system is an excellent example of satellite communication between vehicles and passengers.

Another GPS-GSM tracking system was developed by Pankaj Verma et al. (2013). And the main idea of this system is to control the theft of vehicles in a city; the system uses a microcontroller in addition to GPS and GSM models, as well as a web service for data presentation. Some actual data is provided by the author that shows the history of the route of a vehicle. This system offers an exemplary implementation of the vehicle tracking system but lacks real-time monitoring of cars. In many cases, while developing such systems, we also have to consider the battery connection of the microcontroller units, it is not practical to power these units using small batteries in the car, but else we must power these devices using the vehicle battery. For example, once the driver starts the car engine, the system is powered on automatically, providing a sustainable way of implementing these devices. The main concept for the proposed system by Vatti R. et al. (2014) is to install a GPS and GSM-based modules tracking system in vehicles to track the movement of cars and to provide a service to drivers if their vehicles are stolen. However, a microcontroller was used in developing this system in addition to a GPS and GSM modules. The project was successfully implemented for vehicles unit only, and there was no tracking software or database for storing this information. Thus, it is included in their future work.

Moreover, developing this kind of system has more potential than only tracking the theft of vehicles. A software for car tracking devices designed by Adekunle A. et al. (2015) was created mainly for tracking the theft of cars in Nigeria. This project describes the different uses of old anti-theft techniques, such as vehicle alarms to keep thieves from stealing the vehicle, a centralized locking system, a brake and clutch pedal locking system, and a steering lock that locks the steering column. Furthermore, the project aim is to develop a simulator using MATLAB software to track vehicles in a designed city or neighborhood based on tracker identification which can be the chassis number of a car. As shown in Figure 11 and after granting access to the user (the traffic department or the vehicle owner), the software provides information on a map describing the vehicle’s exact location. In addition to this information, a street name, time, distance, and velocity can be viewed in real-time. This system is a good way of presenting real-time traffic on a map, but the mention of tracking a more significant number of cars and the effect of delays on the system might be more helpful for future studies.

Figure 11 MATLAB VEHICLE TRACKER SIMULATOR

Another scheme for tracking public vehicles (trains) that were developed by Mishra D. et al. (2012) is the use of GPS and RFID to provide accurate information to passengers on arrival timing and stops of trains, making it easy for them to arrive at the stations on time, and eliminate train stations congestion. This system uses short-range radio transmitters and receivers to retrieve information about the presence of trains and other public transport near that station. In the implementation of this project, they provided each vehicle with an RFID transmitter and installed microcontrollers in each bus or train stop that integrate an RFID receiver and a GSM module for sending and receiving data. That said, any bus or train near the stations will send the status to the next stations in that city, allowing passengers to view the estimated time of train arrival, delays, and route change information. Nevertheless, the proposed system will enable us to use different technologies for exchanging information, such as SMS and RFID. Figure 12 shows a simulation result example of the developed project.

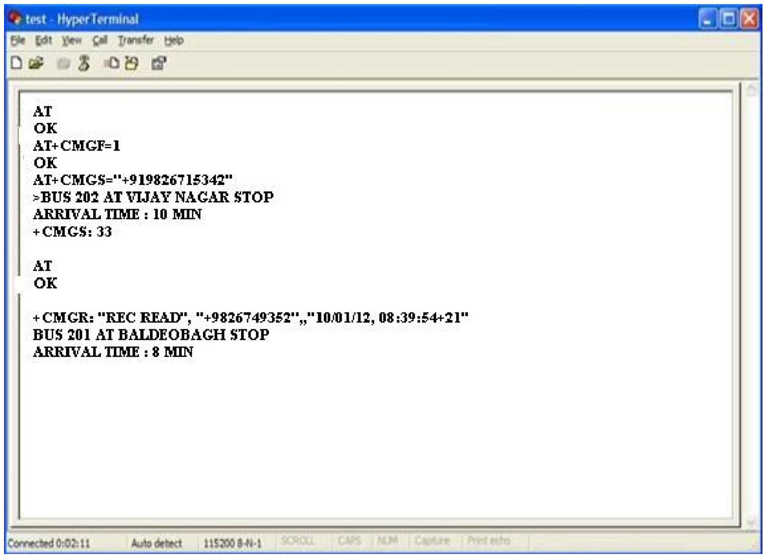

Figure 12 Simulation of a Bus Arrival Time

The system proposed by D. Sudharsan et al. (2012) is developed using Xbee-enabled devices and a GPS to locate the current location of vehicles, as well as a Graphical User Interface (GUI) system to view the data. All the collected GPS coordinates are transferred and stored in a web-based server for easy access and presentation; a database management system using PHPMyAdmin to store the location of vehicles is suitable for storing this information. However, the system mainly studies the delays and packet losses that occur during the communication of coordinates data, as well as the building of a cost-effective tracking system that eliminate the need for tracking maps such as Google maps and Google earth but uses an open-source Geographical Information System (GIS) tools for the use of more accurate real-time representation of location coordinates. Similarly, a third-party company called Sonik GPS Solutions that developed a GPS called "Sonik GPS" has been in the market for providing GPS tracking hardware, software, and a backend server. This service enables users from companies, vehicle owners, and bikers to attach the system to their vehicles for real-time tracking and monitoring.

An interesting study was done by Kim J. et al. (2018) for the analysis of drivers' behaviors based on their driving speeds; the concept of the connected car in this study was able to collect and communicate information for understanding the vehicle maintenance mechanisms based on road conditions, vehicle condition, vehicle models, and drivers' behaviors while driving. The data in this analysis was collected using the onboard diagnostics (OBD) scanner and data communication using wireless technologies. Moreover, the main role of this study is to determine how this data contributes to and creates business value through the wide use of applications this information can provide. The availability of prognostics and health management data to connected cars may help companies provide accurate maintenance information to their customers. The development of a vehicle tracking system with low-cost wireless communication that was done by Osman Ulkir et al. (2020) has described how to connect the tracking device inside a vehicle using the OBD socket, which can power the microcontroller and collect information for transmission through a wireless module. The idea of the system is to reduce the cost of real-time data transmission by collecting the data internally in the car. Once the vehicles reach a data collection station, information can be transmitted to the desired party as a report containing vehicle conditions and fuel usage. For more detailed information about this study, the vehicle tracking term in this study is used to track maintenance information, which may be vague to some readers.

Furthermore, no examples of generated reports were shown in this study, only a description of the system and how to connect it to the vehicle. The benefits of connected vehicles that were described by Karmanska A. (2021) have huge attention from governments while implementing technologies can help in increasing the efficiency of the whole transport system in a city, while using the smart vehicles approach may contribute as well to reducing carbon emissions caused by the overuse of vehicles, reduce the amount wasted on roads, and decreases the traffic noise. This study explored the advantages of using connected vehicles within a city by conducting surveys from different areas, such as 1) the benefits of technologies in cars and 2) the knowledge of connected vehicles. Findings from these surveys showed that the main interest of people was in the benefits of navigation and assistance in parking as well as the implementation of these technologies should be included in all organizations for tracking and monitoring of fleet.

In the search for the different vehicle-to-everything (V2X) communications technologies, Yogarayan S. et al. (2021) have evaluated the V2X communication technologies that are used in Intelligent Transport Systems (ITS) in different countries and categorize the adaptability of the Dedicated Short Range Communication (DSRC) for vehicles, the used cellular networks, and using what they call it a hybrid method which integrates using all these technologies or some of them to achieve a successful, intelligent transport system. However, the article discusses that

DSRC is used not only for V2V communication but also for mid-range communication to allow data collection from vehicles to infrastructure. Countries around the world allocate different radio spectrums for DSRC, such as China which uses 20 MHz for DSRC at around 6 GHz bandwidth. On the other hand, the research suggested that using a 4G/5G cellular network for automobiles will be highly recommended for intelligent transport systems since millions of vehicles are already connected using these networks. By 2025, vehicles will expand their connectivity through 4G/5G networks. The study finally suggests using hybrid communication for vehicles and integrating both DSRC and cellular networks to increase the efficiency of V2X communication. As a result, the article was able to summarize the challenges V2X communication networks might face while deploying them into vehicles, such as the policies government must allow enabling the use of DSRC spectrum and cellular networks for vehicles, delays in data transmission might affect the vehicle's ability to communicate with the infrastructure, vehicles or pedestrians which might cause non-avoidance of accidents and finally the maintenance and implementation cost of V2X communication that can negatively impact the deployment of ITS systems.

A similar project was implemented by Ali, S. et al. (2021) in Iraq to demonstrate a communication module for V2X applications using microprocessors; the designed system architecture, as shown in Figure 13, connects multiple modules inside the vehicle and reads the data using OBDII interface to retrieve vehicle speed, temperature sensor, and much other information. Furthermore, the system can get information from the GPS module and connects to the internet using a GSM/GPRS module to send data, such as the coordinates, to the database storage. They were able to achieve what is required to do to make vehicles smart and communicate with other systems. Still, it lacks many other useful sensors that can be used along with the microcontroller they proposed, such as distance measurement using LiDAR sensors and object detection using a camera module to collect more helpful information about the road and the surroundings. But they only used a GPS module, a GSM module, and an OBDII reader only to read vehicle speed and location.

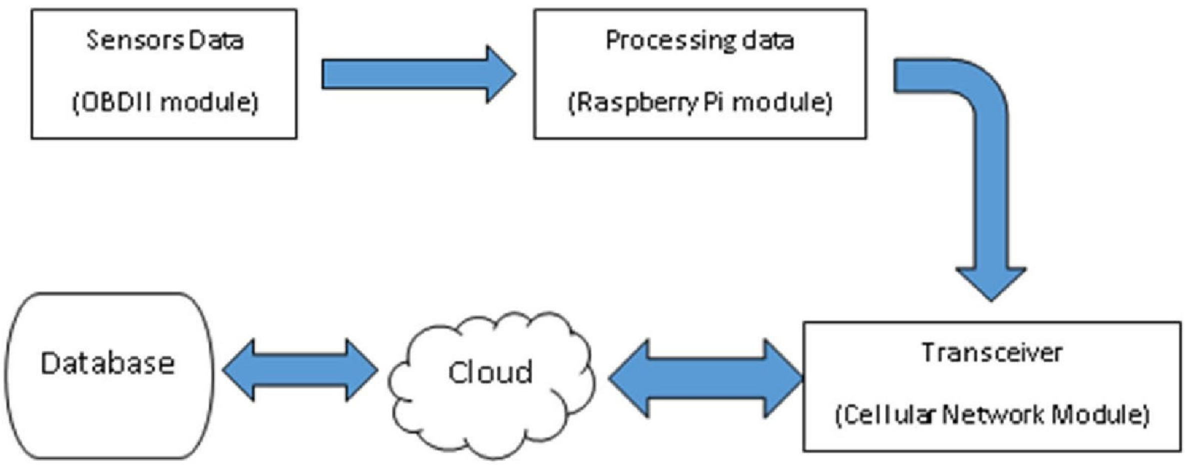

Figure 13 System Architecture Design by Ali S. et al. (2021)

The article prepared by Yogarayan S. et al. (2020) proposes hybrid connectivity for vehicles in the city. That is a combination of Wireless Fidelity Communication (Wi-Fi) to provide a medium-range connection between vehicles and Light Fidelity Communication (Li-Fi) for short-range connectivity. The article then proposed a solution for all vehicles to be equipped with Wi-Fi and LiFi connectivity to communicate with vehicles. Figure 14 shows how the study implemented multiple devices with hybrid connectivity. However, this study aims to compare and propose using other means of connectivity, such as 3G/4G with Wi-Fi/LiFi, for better connectivity and a better intelligent transport system.

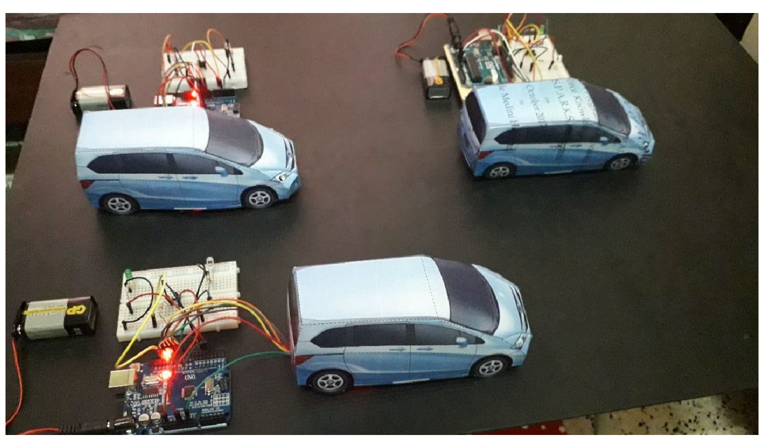

Figure 14 WiFi Communication Amongst Vehicles

The article proposed by Rahim N. et al. (2022) on using 6G networks for V2X communication with other vehicles and pedestrians has multiple challenges and opportunities. Some of the difficulties of V2V communication are the blockage of signals between vehicles by buildings and other obstacles in the city. To overcome such challenges, the writers proposed a possible technique to install Intelligent Reflective Surfaces (IRSs) on corners of obstacles to allow vehicles to communicate with each other even if they are not in sight. Furthermore, the 6G network can provide more applications to V2X, such as integrated computing for V2X, integrated sensing, brain-vehicle interfacing for people with disabilities, and more advanced communication protocols for more advanced connectivity to vehicles. The article then provides different technologies in addition to the 6G networks for V2X communication which can be satellite communication or Unmanned Aerial Vehicles (UAVs) acting as a radio access point for 6G networks to allow vehicles to be more in range to access and view vehicles nearby. The technologies the article proposed require a huge budget in the city; implementing IRSs on each corner of the road, using UAVs, and the use of 6G networks can create a burden on companies or even governments to implement. However, the 2G and 3G networks can be sufficient to communicate with other vehicles, pedestrians, or command centers during the transfer of small amounts of data from vehicles to reduce the cost of devices' installation and to cope with the city budget. Moreover, the 6G networks, UAVs, and IRSs maintenance can increase city expenditures in the future.

A system developed by Haque K. et al. (2020) addresses the communication challenges that V2V and V2I can face while communicating with other vehicles and other objects by implementing Device-to-Device (D2D) communication without using Long-Range Radio (LoRA) WAN communication. The article also mentions that V2I communication help vehicles avoid accidents and congestion to make it possible to reduce these challenges in cities. Moreover, the system architecture proposed by the article shown in Figure 15 is a presentation of how vehicles will interact with other vehicles through the use of Road Side Units (RSUs); this will increase the challenges of vehicle communication with cars that are outside the range (40m) and to be precise, the architecture as described consists of many steps for sending and receiving data from one vehicle to another through RSUs, this will create an overload of data transmission, and it won't be reliable if, for example, more than ten cars are communicating with the same RSU.

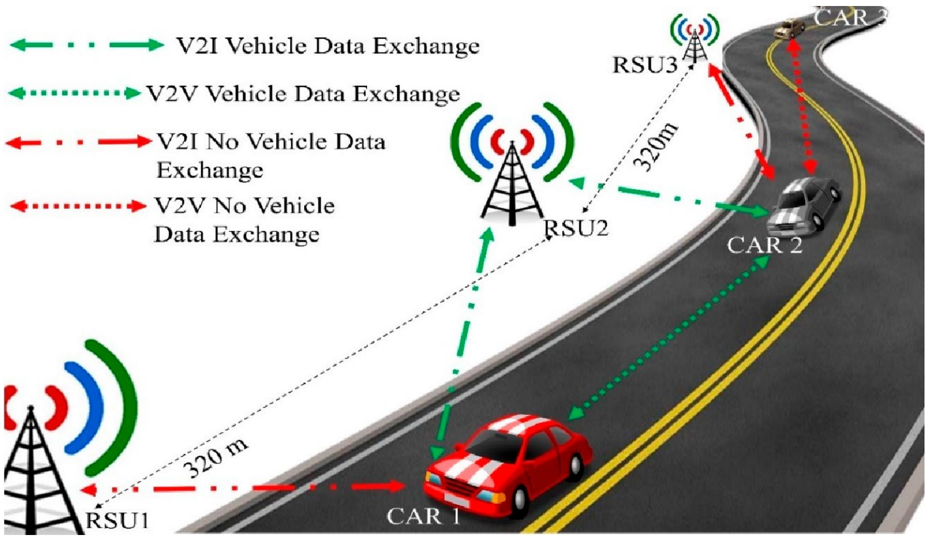

Figure 15 V2X Communication Architecture

The proposed project has successfully implemented a prototype that consists of an On-Board Unit (OBU), as shown in Figure 16, which is attached to a vehicle and incorporates multiple sensors such as the LoRA module, GPS module, MCU units, and a battery for power to test the data transmission between OBU and RSUs on roads using a specific structure for data packets. In a summary of the article, they showed an interesting result while implementing and testing this system in a real-life scenario while collecting data and analyzing it and the power consumed for each device. The system proves that the LoRa protocol provides a robust communication technique for V2X technology. The researchers could also provide more information about using multiple OBUs and RSUs communication since they only tested the prototype on a single vehicle and numerous RSUs. Installation of this prototype on many vehicles will provide more data and can be analyzed to test multiple cars on the same road. For example, OBUs installed on ten vehicles driving on the same street and connected to the same RSUs in case of traffic congestion or different speeds. Deploying such a scenario may provide us with more information about the data transmission reliability of the LoRa protocol and how it reacts to large data transmissions on multiple vehicles connected to the same RSUs. Finally, the researchers tested only the V2V and V2I communication. Still, when the time comes to implement a command center or a platform for road traffic management, this might create a challenge for data traffic management because of the big data required to be transmitted not only between vehicles but also to pedestrians and the cloud.

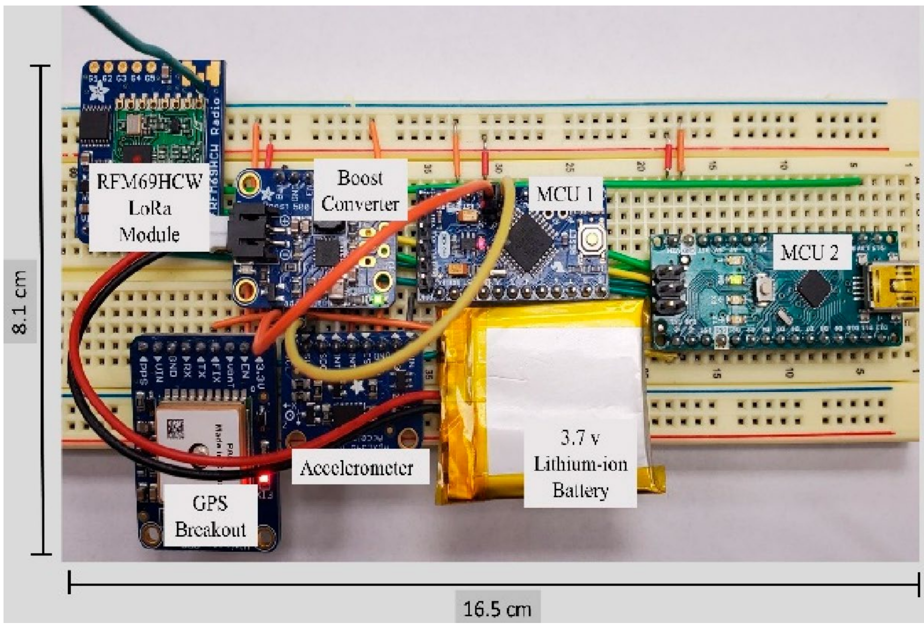

Figure 16 Proposed On-Board Unit (OBU)

C-V2X allows traffic or communication through the LTE network for using the 3GPP release 14 and in the future, the 5G mobile network where the cellular V2X is designed for connecting the vehicle directly with one another and with the help of the infrastructure and the further road users. In a V2X system, the entire data can be exchanged with the assistance of the vehicle sensors with the help of high bandwidth and high-reliability links. Thus, according to Raza et al. (2018), every car contains a sensor that sends data to each zone and the infrastructure, including traffic lights, pedestrians, parking spaces, and more. The U.S. department of transportation estimates V2X technology that might reduce the 'unimpaired driver crashes' by around 80%, where all the traffic participants may become able to predict and perceive the behavior of each other on the road by reducing the crashes, other inefficiencies and the congestion too.

The 'vehicle-to-network' technology expands on V2I and V2V by adding a complete connection layer between the data centers, the car, and the cellular networks. Thus, it can reduce the thorough delay in transmitting the information by showing real-time traffic based on the driver's information. Alongside this, the 'intelligent transportation systems (ITSs) possess the services for improving the safety and security of the traffic through increasing the required efficiency and the examples relating to 'vehicle-to-vehicle communication' that is proposed for safety help transmit messages to the vehicles behind during the existence of the car in the front brakes. On the other hand, as reflected by Huang et al. (2020), V2V communication enables the motor vehicle to access adequate information regarding knowing the position and speed of the other V2V-enabled devices surrounding it using a thorough wireless communication protocol. Henceforth, the data used for alerting the devices of the potential dangers where the reduction rate of accidents also helps reduce traffic congestion.

The V2I communication enabled by a combination of the systems is software, hardware, and firmware. The typical wireless and bi-directional infrastructure-based components are related to the lane markings, traffic lights, and road signs that may provide the information wirelessly to the vehicle and much more. As stated by Farsimadan et al. (2021), 'vehicle communication systems are associated with the computer networks where the vehicles and the roadside units have been familiar with the communication nodes that provide the required information to one another regarding safety warnings and the information relating to traffic. This way, that information, and the safety warnings can effectively avoid such accidents and traffic congestion. Thus, the 'operating vehicle control devices used for operating a vehicle include the steering wheel, gear selector level, speed control, and the organization switch, where the brake pedals and the accelerator may also be associated.

The 'vehicle-to-network' (V2N) is almost like the other forms of V2X technology that connect a vehicle to the surroundings, where the data behind V2N is comparatively more expensive. Besides, this approved network connects a vehicle to the data centers, the road infrastructure, and other cars. V2I connects to the technology that captures the vehicle-generated data, which delivers information regarding the infrastructure to the driver. However, as argued by Hasan et al. (2020), the V2X means that the 'vehicle-to-everything' that itself is a collective term for the technology in which the energy is stored within the electric vehicle (EV) battery that may be exported and used in a house through the other buildings for helping in balancing the electricity grid. The 'vehicle-to-X-technology' is beneficial for reducing the number of deaths by making the visible and invisible both where the electronic emergency brake light warns the driver, and this technology also assists the driver in texting the road hazards.

The V2V communication-based technology may enhance the overall performance of the systems relating to vehicle safety to help it to save lives. 'Intelligent connected vehicles (ICVs) are 'emerging products' for accelerating cross-border integration along with the transformation within the communication, information and big data, road transportation industries, internet, and artificial intelligence. As illustrated by Salman et al. (2018), the challenges or the drawbacks of V2X communication where the vehicles in V2X are entirely connected to the internet, where those are inclined to hacking and the hackers also may access and control the vehicle and the privacy of the owners, as well as the users of the vehicles, have the major concerns. The wireless communication technologies that are recently used for connecting to the vehicle include 'dedicated short-range communications (DSRC), 'cellular-vehicle-to-everything (C-V2X) communication, and Wi-Fi 6 mainly. The V2V communications enable the vehicles to transmit the data over a wireless mesh network for sending, retransmitting, and receiving the signals where the nodes may collect the traffic conditions several miles ahead of a driver that requires sufficient time for the unhinged drivers in terms of managing the drives.

The entire goal of V2V communication is to prevent accidents by allowing the vehicles to transmit and send the positions and speed of the data to one another over an ad hoc mesh network. Henceforth, the V2P (vehicle-to-Pedestrian) and V2X directly involve the communications between the pedestrian and the vehicle or the multiple pedestrians within the dimensions of proximity. However, as contradicted by Lu et al. (2021), the communication can also be represented to other 'vulnerable road users where the V2P can also be conducted directly through the usage and application of the network infrastructure. The i2i communication communicates the modality for employing the electrical signals for conducting that between the implanted LPs. The V2X systems tend to share adequate information associated with the speed and the other entities that are around the vehicle, where the information increases the awareness of the drivers regarding things such as nearby accidents, approaching emergency vehicles, road conditions, and the roadworks notices and activities of the other drivers on the same routes (Rasheed, 2022)

Chapter 3: Description of System Architecture

3. System Architecture

This system architecture will help give an overall idea about the whole system since it provides a picture of the main components to make it possible to visualize the devices and sensors used. Hence, dividing the architecture into three layers can separate the services and devices and categorize each to focus on developing every component and showing how they relate.

Similar to any developed system. The system architecture implemented in this project is categorized into three different layers. The vehicle agent system, network layer, and application service as shown in Figure 17. Each of these layers has functionality and connectivity to work with other layers and applications to complete the system. However, this section will discuss each of these layers in detail (from the bottom to the top), including the devices and sensors used, the technologies and terms, descriptions of each technology, and the purpose of their uses.

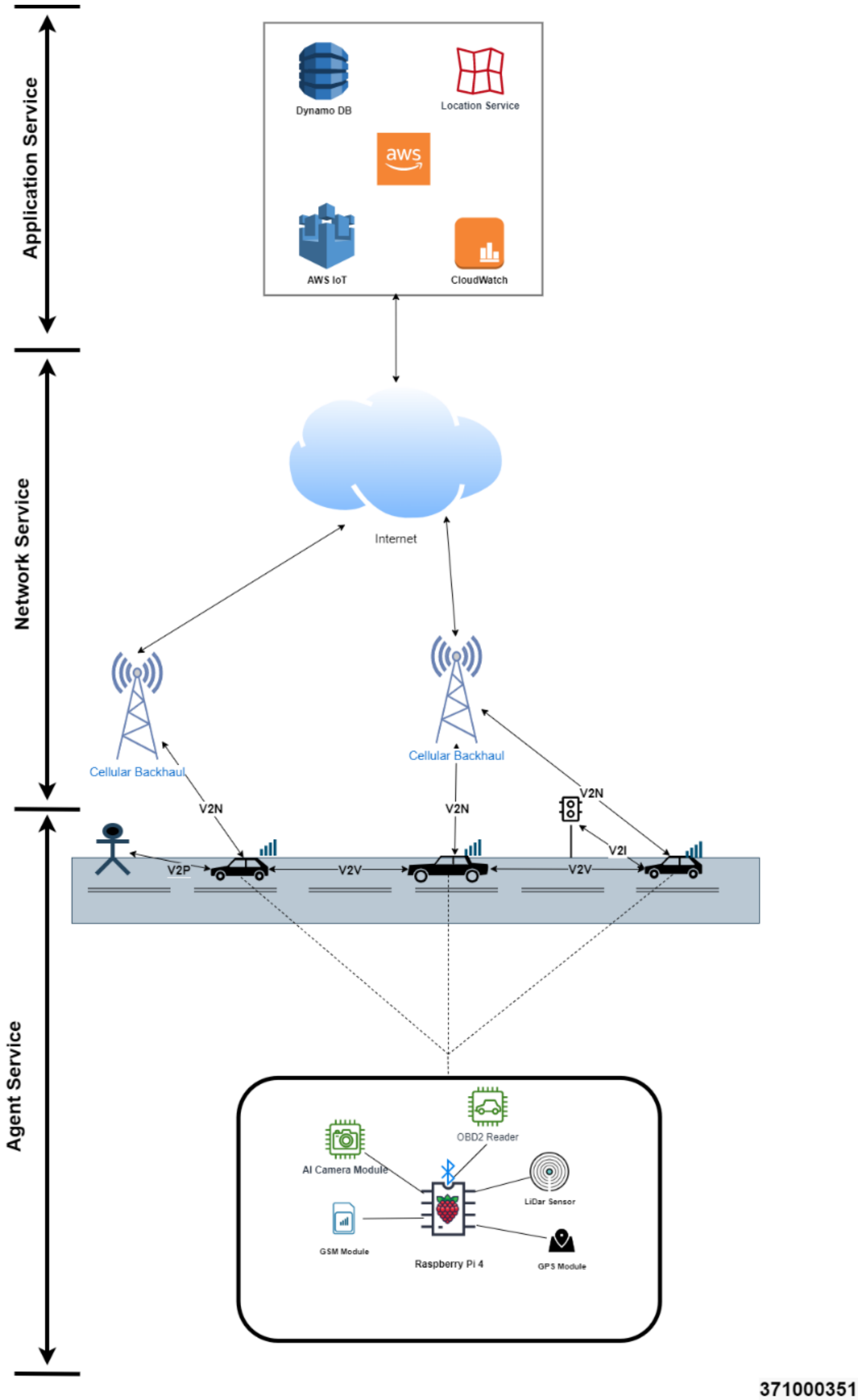

Figure 17 Proposed V2X Architecture

3.1 Agent Service (Physical Layer)

The vehicle agent service is also referred to as the physical layer of the system because of its components and the interaction with low-level devices and programming software. As the physical layer is the brain component of the whole architecture, its functions range from collecting information from the vehicle, such as vehicle speed and engine status, to providing internet connection and monitoring the device location in addition to providing a continuous power supply whenever the vehicle's engine is ignited. On the other hand, interfacing multiple sensors and modules to combine them into a single system can be challenging due to the compatibility of modules with each other or with the main component (the Raspberry Pi microprocessor). For instance, the camera module's version must be over-checked before purchase to ensure its compatibility with the version of the microprocessor. After gathering the sensors and modules, the next step is to wire and program these devices to collect the required data. However, this will be further discussed in the Implementation chapter.

3.1.1 Raspberry Pi Microprocessor

According to Lowe D. (2017), the Raspberry Pi is a complete mini-computer system that consists of a Random Access Memory (RAM), a Central Processing Unit (CPU), a storage device, along with many input/output pins, USB ports, HDMI port, and a network connection. The microprocessor is reliably used for creating gadgets and demonstrating projects and ideas with the ability to connect multiple devices and sensors that the operating system can control. However, Figure 18 shows the programmable device with its components and features that can be used with other devices and software. In this project, two Raspberry Pi computers might be used because of the limited number of sensors each microprocessor can support. Moreover, each Raspberry Pi has limited processing and memory capabilities, which can result in slow data processing. Using two of them can lower the processing load of external connected sensors.

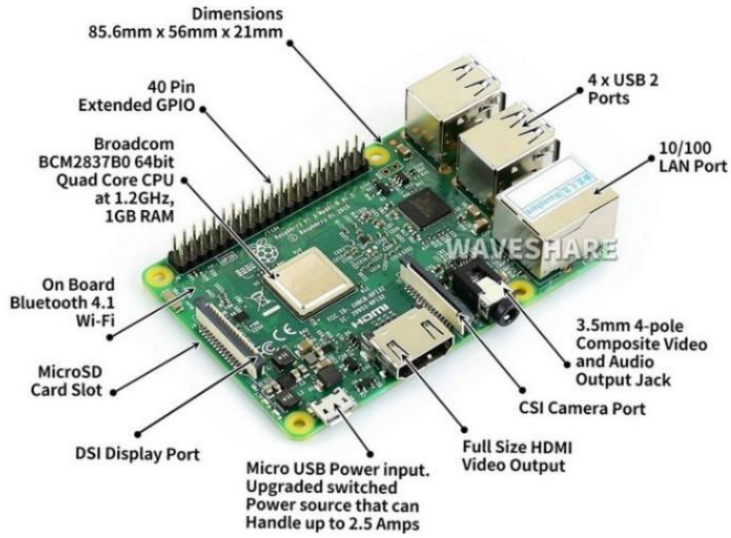

Figure 18 Raspberry Pi Features

3.1.2 Camera Module

The Raspberry Pi can provide two connection options for the camera module. Connecting a camera module to the CSI Camera Port, as shown in Figure 19, this camera type is called the PiCamera, designed mostly for microprocessors that support these ports or connecting a regular web camera to one of the USB 2 ports.

Figure 19 PiCamera Module Connected to Raspberry Pi

During the implementation of this project, a simple web camera connected to the USB port will be used for object detection purposes, such as detecting vehicles, traffic signs, road hazards, and different types of infrastructure images that will be discussed more in the Implementation chapter.

3.1.3 OBD2 Scanner

On Board Diagnostics version 2 is a built-in system in every vehicle that provide information and diagnostics to monitor faults or record data of the car's components. Once the vehicle starts, this system begins scanning all of the car's subsystems to check for defects, safety components, and almost every device that makes vehicles run. In the implementation of the prototype, a Bluetooth OBD2 will be used, as shown in Figure 8 and Figure 20, to retrieve information from the vehicle, such as vehicle speed and emission control system readings, to later pass it to the brain system (the Raspberry Pi).

Selecting the Bluetooth option for OBD2 will provide more efficient readings and minimize cable management while setting up the vehicle agent. The wireless communication will not only benefit the system but also offer readings to the drivers about major issues in the vehicle. But for this study, a few readings will be fetched from the vehicle for further processing.

Figure 20 OBDII Scanner and Location in Vehicles

3.1.4 LiDAR Sensor

According to Wasser L. (2022), a Light Detection and Ranging (LiDAR) sensor is an active remote sensing system that uses light energy to measure distance and identify objects. The light travels outside the LiDAR sensor, and once it touches or detects an object, it reflects to the same sensor calculating the travel time, then can be used to measure distance or draw objects. Figure 21 provides an idea of how the LiDAR system is used in vehicles to detect other objects on the road. However, many LiDAR systems are available for different uses, such as 360-degree scanning to detect multiple objects, which can be used in different industries, and single-point LiDAR scanning for accurate distance measurements. On the other hand, this project uses the single-point LiDAR sensor, as shown in Figure 6, to allow accurate distance reading between the vehicles, pedestrians, and any objects in the front or backside of the car.

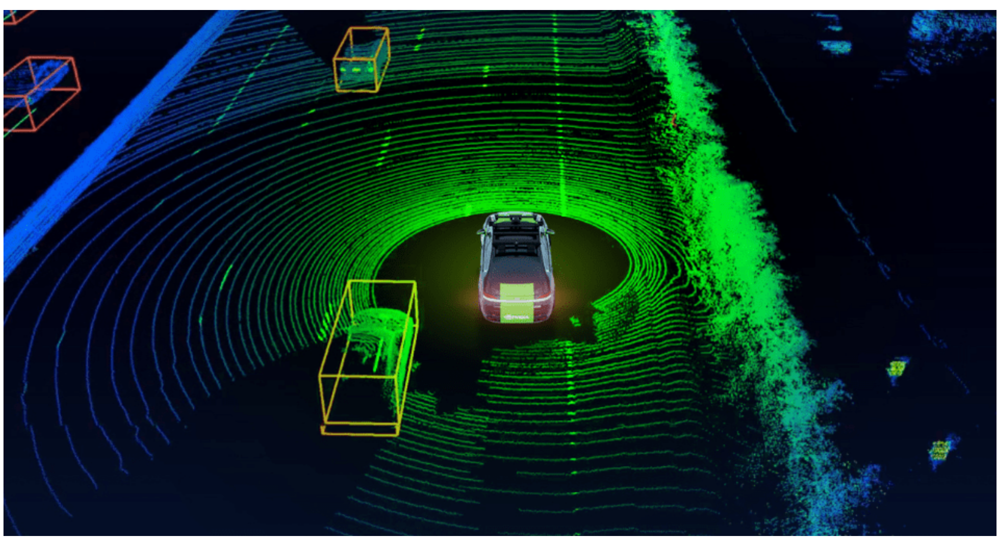

Figure 21 LiDAR Sensor Object Detecting

3.1.5 GSM SIM 900 Module

The Global System for Mobile Communication (GSM) module is a small, cheap device designed to work with IoT sensors and applications. It allows Internet of Things (IoT) devices to send/receive notifications or connect to the internet for data transmission from anywhere in the world. Cellular backhauls are a network of towers that provide coverage to these modules and ensure they are connected at all times. The system architecture in Figure 24 shows a simple description of how multiple GSM modules are connected to these towers. And each of these towers provides coverage of a maximum radius of around 13 miles, according to Lockle P. (2012), which also depends on the technology used and the type of tower. Figure 22 provides an idea of the coverage of a single cellular tower that devices will be connected to while they're on the range.

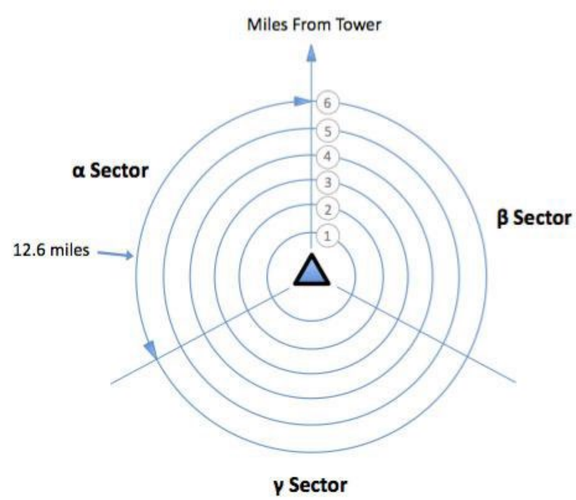

Figure 22 Single Cellular Tower

In this project, the vehicles will be connected to the internet to transmit data using these GSM modules with a SIM card that is subscribed to an internet plan. The system doesn't necessarily require a 4G or 5G connection, but a simple 2G or 3G can be sufficient since we are transmitting a small amount of data at a rate of time. For example, sending the GPS coordinates to a database storage every 2-5 seconds or transmitting sensor temperatures' state every 30 minutes or only at specific triggers. By doing that, we can reduce the network load from the millions of cars in the city.

3.1.6 Ublox Noe-6 GPS Module

The Ublox Global Positioning System Neo-6 provides accurate location services designed to be interfaced with a microcontroller or a microprocessor. This module can help locate vehicles for location and traffic congestion analysis while installed in all vehicles in the smart city and using satellite communication to receive the coordinates. Figure 23 describes the Neo-6 GPS module and its respective connections and parts.

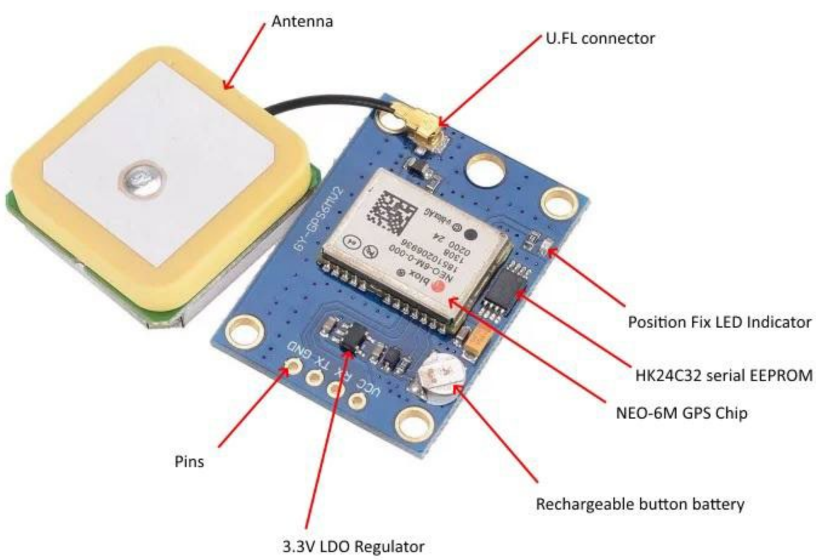

Figure 23 Neo-6 GPS Module Description

Acquiring the coordinates from the GPS module will not only provide location information of vehicles for traffic congestion but will also help improve the security of cars in the city by enabling drivers to locate their stolen vehicles or exactly where they've parked. The GPS module can provide many applications, but in this project, I will only use the module to acquire the coordinates (latitude and longitude) to interactively track the traffic in real-time and collect data about road conditions.

3.2 Network Service

Communicating between the agent and application services for sending and receiving data requires a reliable internet connection. As discussed before, to connect the vehicle agent to the internet, we use the GSM module with a SIM card that is subscribed to internet service from the internet service provider. Moreover, establishing the connection between those two services go through multiple steps ranging from powering up the device to creating data packets to prepare it to be sent to the server. In this sub-section, the network service will be discussed in detail, going through all the steps to accomplish a successful data transmission using the GSM module.

The GSM module is used for sending/receiving text messages and calls. The module used in this project includes a General Packet Radio Service (GPRS) service, a mobile communication standard that uses 2G and 3G networks for internet connection. This standard enables the transfer of compressed data packets to be communicated and sent to the destination. As shown in Figure 24 and according to BasuMallik C. (2022), the GPRS modules are connected to multiple devices, and these devices can range from mobile phones to computers that support these modules. However, the GPRS network consists of multiple stations that cover almost all the city areas to receive the data from the modules and create a connection to the internet through the GPRS gateways.

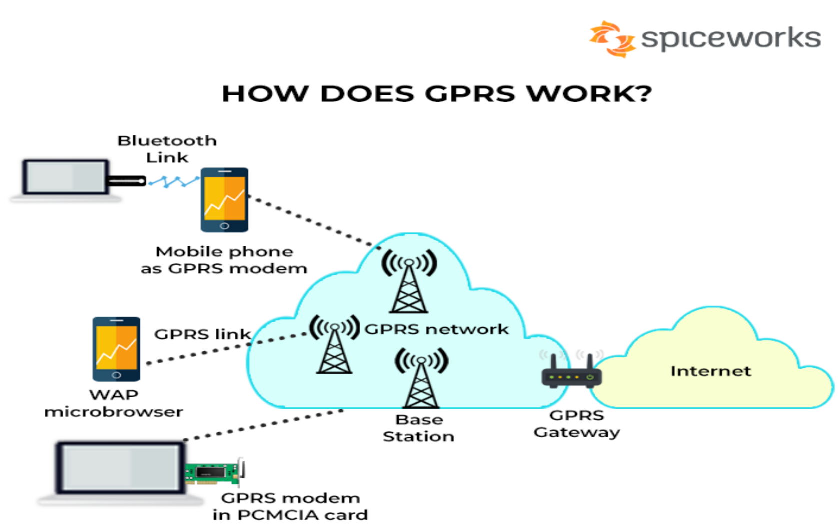

Figure 24 GPRS Connection Establishment for IoT

If we take an example of a service provider such as Etisalat in Dubai, we can see the 2G and 3G network coverage in Figure 25 and how all the roads are mostly covered with the spread of cellular towers. This shows us that by implementing the vehicle agent with the use of a GSM/GPRS module for internet connection, there won't be many challenges in connectivity since the connection must be stable most of the time.

The vehicle agent can be altered if connection issues occur by saving the required information locally on the microprocessor until the connection is back up.

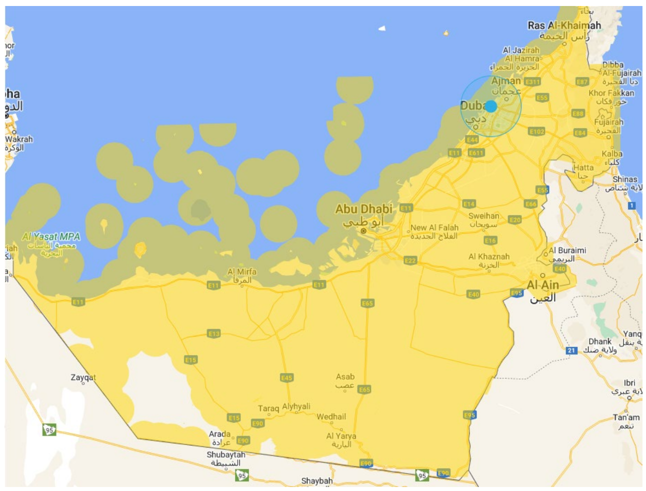

Figure 25 Etisalat 2G & 3G Coverage (Source: Etisalat.ae)

3.3 Application Service

The application service monitors city traffic through the vehicle agent device, providing a reliable data source. This service can view and analyze data to be visualized into beneficial information. Yet, the application service consists of multiple combined services and applications to implement this layer. In this project, the deployment of the application layer was not possible due to time constraints but will be discussed in detail in the implementation chapter.

The subsections below discuss each application layer component to identify how the different Amazon Web Services (AWS) platforms can be combined and used as a road and traffic management platform.

3.3.1 Amazon DynamoDB Storage

It is a requirement for the collected data from the vehicle agent to be stored for either future access, real-time data visualization, or analysis of data. The DynamoDB, according to Carty D. (2017), is a fully managed no SQL database with a low delay in processing and receiving data into the database. It can be reliable for Internet of Things (IoT) devices and sensors' data since they demand a speed data transmission for real-time visualization. DynamoDB uses simple queries such as GET and PUT to fetch or publish data to tables in the database with simple instructions without using traditional relational databases that create latency with big data. In this project, the database is used to store the GPS coordinates in real-time; the real-time storage here means that the coordinates will be stored and updated every few seconds without storing their history. By saying that, we can protect the drivers' privacy by only showing the real-time location for traffic analysis purposes. Another table can also be used for LiDAR sensor data to show the measured distance with other vehicles, which can help in traffic analysis. Finally, a table to store any identified object from the camera module that needs attention. For example, if the camera module detected a road hazard. For instance, a blown tire in the middle of a highway; this information can be transmitted and stored in the database storage to view all this information by the Road and Transport Authority.

3.3.2 Amazon Location Service

According to Sandhu S. (n.d.) Amazon location services provide a location map service to plot multiple points to view, track, and route techniques. Amazon Web Services (AWS) location service can supply applications with maps, place indexes, route calculators, geofence collection, and trackers. For this study, it is ideal to use the tracker service since we are trying to track city traffic in real-time. Figure 26 provides an example of an AWS tracker using the AWS location service.

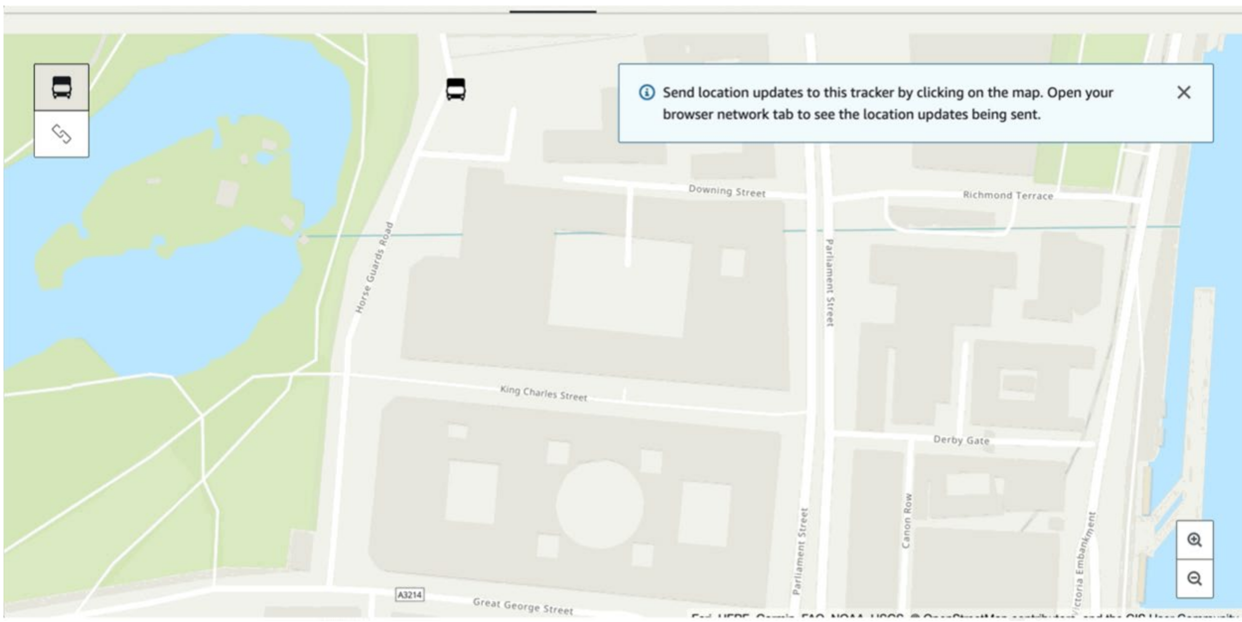

Figure 26 AWS Location Service - Tracker

By interacting with the vehicle agent through the AWS location tracker, we can view vehicles' location in real-time, adding more valuable information such as the distance of the vehicle from other vehicles and important objects near the vehicles that need attention. We can even plot the infrastructure of IoT devices to be viewed on the map.

3.3.3 AWS IoT Service

Amazon Web Service Internet of Things can integrate and manage IoT sensors and devices across the city to interact with the cloud or other devices and sensors. In this project, we can take advantage of the AWS IoT service to collect and analyze the traffic data to provide drivers with the best routes away from traffic, a notification service to acknowledge and notify them of nearby accidents to avoid or collect data about all the vehicle agents and their sensors in the city. Furthermore, the AWS IoT platform can also provide users the ability to configure and manage IoT devices remotely, their certificates, policies, and rules.

3.3.4 Cloud Watch AWS Service

According to Amazon AWS (2022), Amazon Cloud Watch provide product owners with monitoring services to keep track of the connected devices' data allowing them to visualize and collect data in the form of events, metrics, and logs. The collected data can be visualized in the form of dashboards, as shown in Figure 27, as CloudWatch service can help this study by viewing all the sensors' data, required maintenance, and the status of all these devices in one screen. However, this will provide the Road Transport Authority with valuable information about all vehicle agents' status and more analysis of the connected devices.

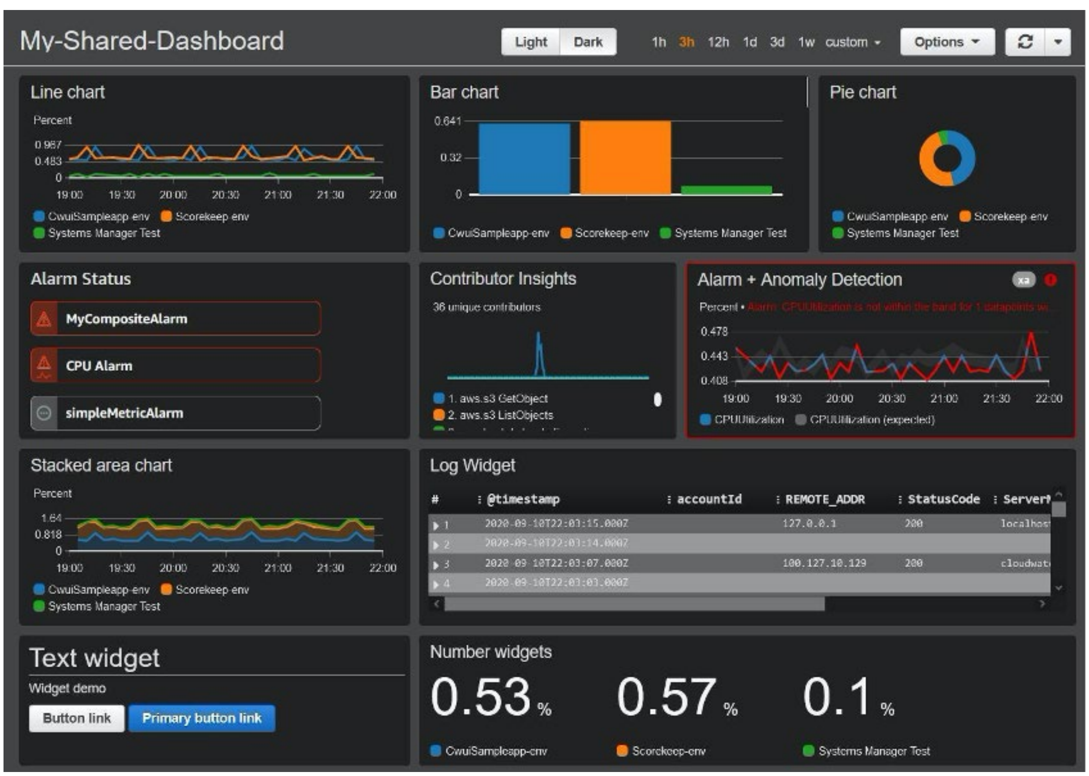

Figure 27 CloudWatch Dashboard Example (Source: Amazon)

Chapter 4: Implementation

The implementation part is the most important area in deploying and analyzing the system to allow us to study the received and processed data further, the time taken to implement each unit and to search for challenges that might occur and how we can overcome these issues. The implementation of this project went through different phases, the implementation of the vehicle agent as the first step, deploying the network connectivity within the system as the network layer, and finally, implementing the platform that can receive, store, and process data on the cloud, but the application platform was implemented as an idea for future improvements.

This chapter will cover only the deployment of the vehicle agent and network layer by detailing how each sensor is wired and connected to the main microprocessor, the connectivity between these sensors to the internet, and what must be included in the application service from data that we can receive and process to visualizing it and making it understandable and readable. Hence, the testing of the V2X communication implemented in this project went through a real-life testing environment, as will be discussed more in this chapter.

4.1 Configuring the Vehicle Agent and Network Layer

4.1.1 Preparing and Configuring the Raspberry Pi Microprocessor

The Raspberry Pi microprocessor must be configured for connectivity and compatibility with other sensors and modules. The below steps have been done to allow the minicomputer to communicate and interact with other modules:

1) Selecting the proper Operating System (OS) to install
2) Configuring internet connectivity to download and install packages
3) Configure the serial ports to enable successful communication with other sensors
4) Deploying OpenCV library for object detection
5) Installing the Pynmea library for receiving GPS coordinates from the GPS module
6) Downloading and installing the Point-to-Point Protocol (PPP) for connecting the Raspberry Pi to the GSM module's internet connection

After properly installing the above packages and software, the microprocessor should be ready to receive and process the data of other sensors connected to it. To maintain the connectivity, we must ensure the serial ports are enabled and configured, and permissions to these ports are always set to 666 (read and write permission to all users on the Raspberry Pi). Finally, configuring the start-up scripts might be very reliable for this prototype since it'll be mobile, and it is practical to start the scripts after the microprocessor boots up.

4.1.2 Connecting the Camera Module

The camera module in this project is used and wired using the USB port in the Raspberry Pi microprocessor, as shown in Figure 28. However, using a web camera can simplify the connectivity to the microprocessor and have more length of the USB wire to mount it on the vehicle dashboard rather than using the PiCamera, which can be exposed to heat or connectivity that can be easily damaged.

Figure 28 Wecamera Module Connected to RPi

A web camera module is used to detect objects while the vehicle is moving around the city, only attaching it to the front direction of the car; the camera can detect street objects such as cars, buses, trucks, traffic signs, road structures, and pedestrians. By detecting these objects, we can collect valuable information to interact with other cars and the people passing on the streets. Figure 29 shows some objects the camera module is trained to detect. Yet, detecting street objects is done using the OpenCV libraries in Python programming language; after training the model to detect these objects, the video frames can show the percentage of detection probability of these objects. For example, if the camera detects a moving person, it will surround the object with a square and give the percentage of its probability to be a person on the top of that square.

By doing that, the camera can self-learn over time to better enhance the detection mechanism and detect objects more accurately. Furthermore, establishing this technique can help us find ways of communicating with other vehicles; instead of using high-cost AI cameras, these budgeted cameras can detect vehicle plate numbers and transfer images to text which will be further discussed in detail in the conclusion and Future Improvements Chapter.

Figure 29 Example of Street Objects Detected using the Camera Module

The object detection in this prototype went through multiple steps using the Raspberry Pi microprocessor and the web camera to program it using Python programming language. The series of steps include:

1) Setting the Camera Size

After running the object detection program, the camera window will pop up, as shown in Figure 29, with a size of 175x175 pixels; this can be increased or decreased depending on the performance of the Raspberry Pi. This project is set with size to reduce the load on the processor since we are using more sensors on the same microprocessor.

2) Capturing Video

When successfully opening the camera window, OpenCV will start streaming the video using the VideoCapture() function to stream all the frames of the web camera to the output screen.

3) Fetching Objects' Names

The objects' names are stored in a separate file and called once the video capturing starts; this file includes all the names of objects which the model is trained to detect. In this prototype, only street objects' names are stored, such as vehicles, trucks, buses, fire hydrants, traffic signals, and traffic signs.

4) Drawing Objects in Rectangles

Rectangles are drawn around the detected objects with a percentage of their probabilities, as shown in Figure 29.

Some of the challenges have been faced during the implementation of the camera module, such as camera delays which could be fixed by lowering the size of the video capturing or using a better microprocessor with more CPU and RAM capacity.

4.1.3 Connecting the LiDAR Sensor

The LiDAR sensor helps detect the distance between the vehicle and nearby objects. In this prototype, the LiDAR sensor is wired with the Raspberry Pi through the USB port and a TTL converter, as shown in Figure 30. This wire will be extended for around 3 meters to the outside of the car and attached to the front of the vehicle.

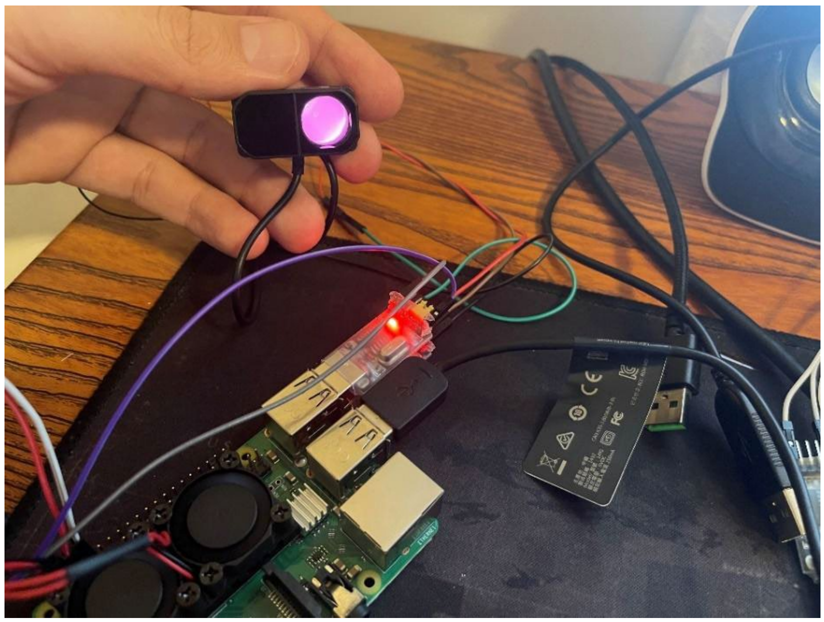

Figure 30 LiDAR Wiring with RPi

However, the received data from the TF Mini Plus sensor is divided into multiple bytes. In Python programming, separating these bytes can return valuable and real-time data such as the sensor's distance, signal strength, and temperature. Figure 31 is an example output of the LiDAR sensor used in this project.

```
Shell
Distance: 0.17 m, Strength: 6085 / 65535 (16-bit), Chip Temperature: 56.0 C
Distance: 0.18 m, Strength: 5028 / 65535 (16-bit), Chip Temperature: 56.0 C
Distance: 2.51 m, Strength: 4887 / 65535 (16-bit), Chip Temperature: 56.0 C
Distance: 2.51 m, Strength: 4863 / 65535 (16-bit), Chip Temperature: 56.0 C
Distance: 2.51 m, Strength: 4852 / 65535 (16-bit), Chip Temperature: 56.0 C
Distance: 2.51 m, Strength: 4841 / 65535 (16-bit), Chip Temperature: 56.0 C
Distance: 2.51 m, Strength: 4833 / 65535 (16-bit), Chip Temperature: 56.0 C
Distance: 2.51 m, Strength: 4835 / 65535 (16-bit), Chip Temperature: 56.0 C
```

Figure 31 LiDAR Sensor Output

4.1.4 Connecting the GPS Module

The GPS Module connection is wired with the Raspberry Pi in the same as the other modules; with the USB TTL proper connection, we will be able to receive the coordinates from the module. The biggest challenge with this module is that it is not designed for an indoor environment, so it should be placed outdoors to allow the signals to travel from the satellites to the module. Figure 32 shows the connection to the GPS module placed in an outdoor testing environment with 3 meters of jumper wires for testing the module. Yet, this long wire is optional while implementing the vehicle agent; because it will be placed inside the vehicle and coordinates will be easily fetched.

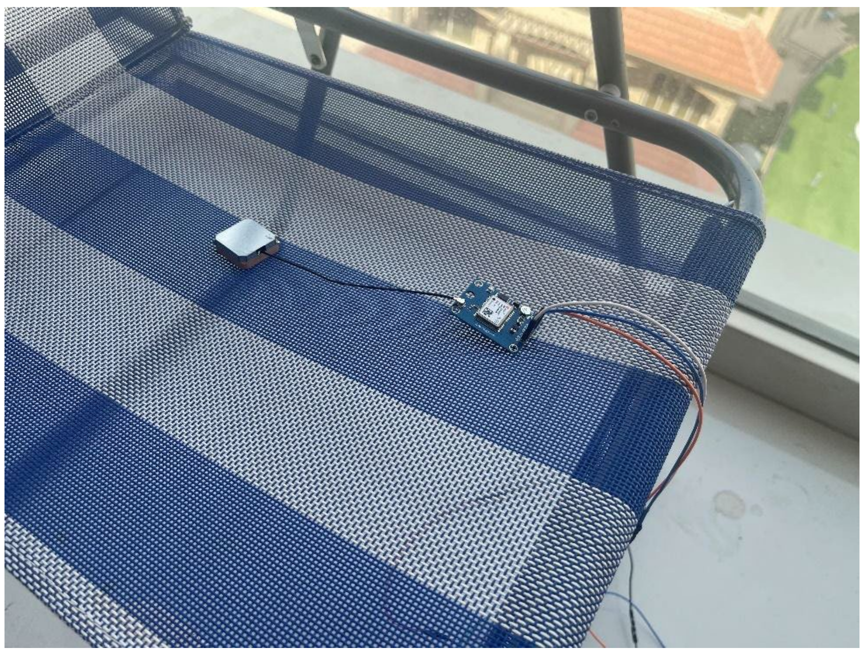

Figure 32 GPS Module Outdoor Environment

While reading the serial data lines received from the GPS module to the Raspberry Pi through the USB port, we can parse this data to be readable by using the PYNMEA2 library. However, when the GPS module detects and receives a signal from satellites, it will start collecting the device's current coordinates containing the latitude and longitude to be received by the microprocessor and viewing it in a readable manner.

Figure 33 shows some of the received coordinates fetched from the Ublox Neo6 GPS module after parsing the raw data from the serial port.

```
>>> %Run GPSCoor_Upload_to_DynamoDB.py
 GPS coordinate Stream:
 latitude: 25.1226755, longitude: 55.40124983333333
 Uploaded
 latitude: 25.1226755, longitude: 55.40124983333333
 latitude: 25.1226755, longitude: 55.40124983333333
```

Figure 33 Example of Received GPS Coordinates

Fetching the vehicle coordinates will help the application platform to receive and visualize the location of vehicles in real-time using any online maps. This will allow us to view vehicles in the city in real-time without disruption, allocate traffic congestion on roads, and ensure roadways are free of accidents. Moreover, the GPS data will be sent from the Raspberry Pi to the database for storage which will be discussed more in the Platform Implementation Section.

4.1.5 OBDII Scanner Connection

As discussed before, the connection between the Raspberry Pi and the OBDII can benefit the vehicle agent with data such as vehicle speed, RPM changes, and different valuable data that can be transmitted to the application service. This data, however, can provide a good deal of information for monitoring and analysis. In this project, the Raspberry Pi, the main computer system, receives the data through the OBDII scanner with a Bluetooth version 4.0 connection. A Bluetooth connection is used for reliability. If, for example, it is required in the future to change or replace the OBD scanner, it can be easily done rather than embedding it into the vehicle agent with a USB connection. Moreover, adding the OBDII scanner with the vehicle agent can provide the most valuable information, such as vehicle speed. However, communicating the vehicle speed with other vehicles enables a prediction of drivers' behaviors and can maintain the distance between cars, especially during traffic congestion.

Figure 34 OBDII Scanner Connection

The below steps are taken to successfully retrieve the vehicle speed from the OBDII scanner to the Raspberry Pi microprocessor:

1) Attach the OBD Scanner to the vehicle as shown in Figure 34
2) Turn on both the vehicle and the Raspberry Pi microprocessor
3) Search for available Bluetooth devices and connect to the OBDII device
4) After the connection is successful and the installation of the required Python packages, we fetch the vehicle speed using the hex code "010D1" from the OBD scanner, as shown in Figure 35
5) Data is ready for transmission

By following these steps, we can retrieve the vehicle speed and any other required data, but this project only claims the vehicle speed to transmit it either to the application layer or to other vehicles to achieve vehicle-to-vehicle communication.

```
22:51:18.728214,         Vehicle Speed,14.9160969546,MPH
22:51:18.858959,      Throttle Position,9.41176470588,%
22:51:18.990455,    Coolant Temperature,81,C
```

Figure 35 Vehicle Speed Returned through OBDII Scanner

4.1.6 Configuring the GSM Module as the Network Layer

The configuration of the GSM SIM900A module, which acts as the network layer in this prototype, is connected directly to the microprocessor to provide the Raspberry Pi with an internet connection. Interfacing the module, as shown in Figure 36, can be challenging since the module requires a good and stable power source. A TTL converter is connected to the module for only 5 volts, and a ground connection is used to achieve this. At the same time, the data transmission is done through the Raspberry Pi GPIOs to ensure a stable and reliable connection; Figure 37 shows a more detailed interface between the GSM module, Raspberry Pi, and TTL adaptor.

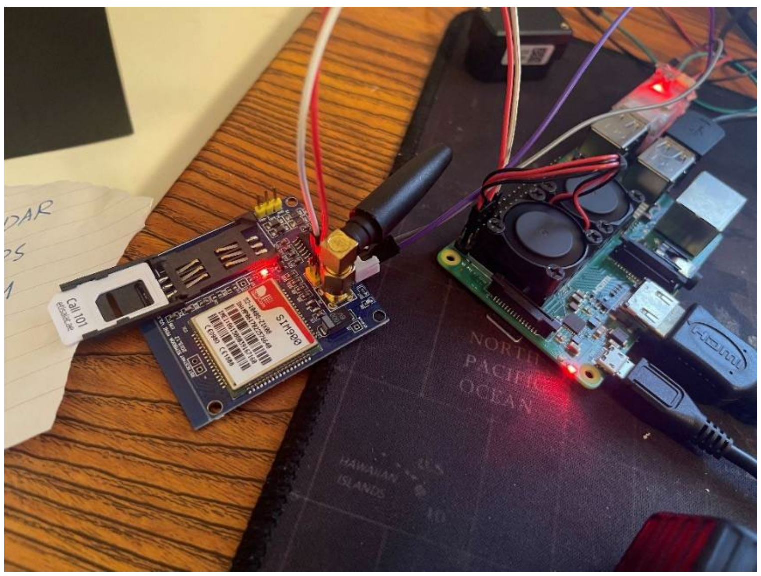

Figure 36 Interfacing GSM SIM900A Module with RPi

After the wiring connection is successful, the software part comes into play. The configuration of the GPS module for internet connectivity is done by installing Point-to-Point Protocol (PPP) in the Raspberry Pi to enable a new network interface. This network interface can act as the network adapter instead of an Ethernet or Wi-Fi connection since the prototype will be installed inside the vehicle, and no use of Ethernet or Wi-Fi is required.

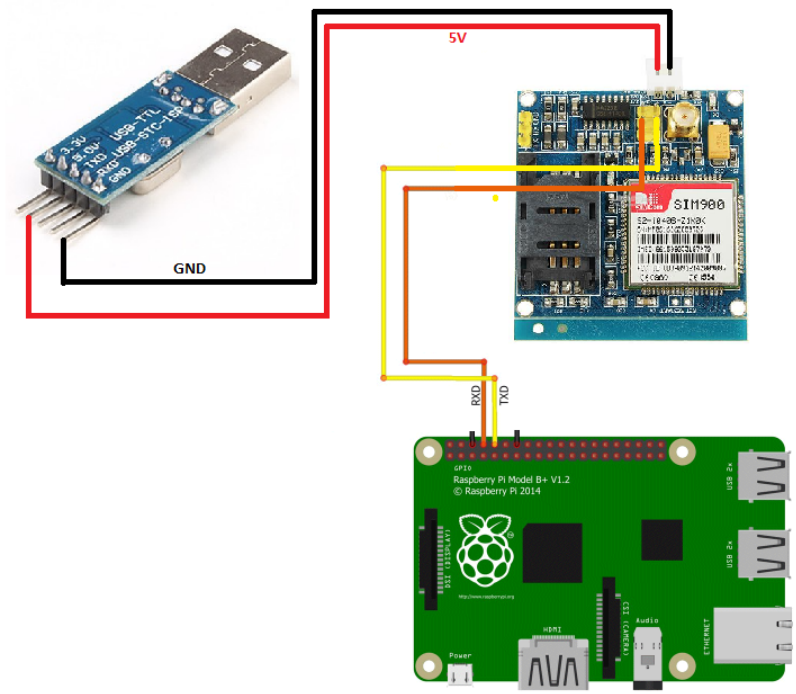

Figure 37 Interfacing SIM900A Module with RPi with a TTL Converter Power Source

After successfully installing the PPP protocol in Raspberry Pi, it is required to configure the PPP network adapter interface with the Internet Service Provider (ISP) Access Point Name (APN). However, the APN is the name of the SIM card's subscription provider. In our case, it is Etisalat, and their APN for internet access is "*Etisalat.ae*". Figure 38 describes the details of the configuration file for the PPP network adapter. Finally, starting the adapter using the pon rnet command will allow the Raspberry Pi to use the GSM module's internet connection even while booting up the microprocessor.

By implementing these steps, connectivity to the internet is established with the Raspberry Pi, along with all the attached sensors can communicate with the application platform for data transmissions such as sending GPS coordinates, LiDAR distance data between the vehicle and other vehicles, and specific objects that are identified from the camera module can all be communicated with the server and database storage.

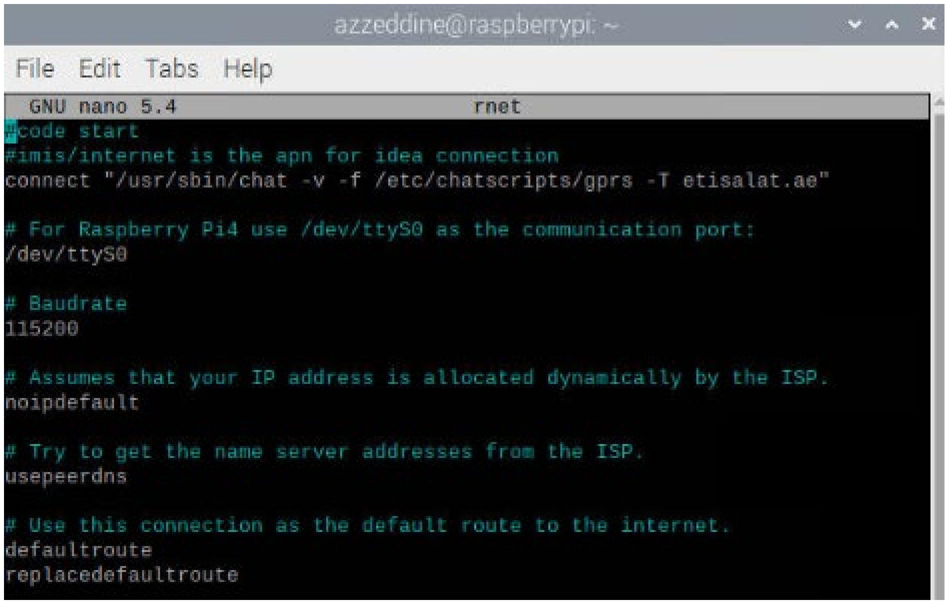

Figure 38 GSM Network Adapter Configuration

To conclude the implementation of the vehicle agent, we have configured and connected different sensors that are used to read vehicle data and prepare them to be sent to the application platform over the internet. That said, communicating such data can help the Road and Transport Authority track traffic congestion through all these connected devices and then analyze this data for future decisions on managing the roads efficiently and reliably. Furthermore, while these sensors can connect to the internet, maintenance and updates are done remotely, which will not affect the visits to the transport authority in case software issues arise. The following section will discuss the implementation of the application layer platform with the data received from the vehicle agent and how it is processed and stored on the cloud.

4.2 Real-Life Scenario Implementation

The implementation of the vehicle agent can give us a great idea of how such systems work and how we can collect data to communicate with vehicles, pedestrians, and infrastructure to allow the deployment of dashboards and application platforms. In this project, testing of vehicle agents took place in a real-life environment to further study and allow future solutions as well as the challenges that might arise while deploying such devices.

This real-life scenario created an environment to test the vehicle agent. Installing the vehicle agent inside a car with a proper installation of cables and power sources, as shown in Figure 39, was successful. Yet, selecting the location of the test environment was around the campus of Rochester Institute of Technology (RIT) Dubai, as shown in Figure 40.

Figure 39 Vehicle Agent Installation Inside a Vehicle

As a result, the vehicle agent worked well and returned a great value of data such as the GPS coordinates, distance of nearby vehicles, and detected street objects from the camera module. This allowed us to view the vehicle's real-time location, whether it was moving or not, and to track the traffic in that area if multiple vehicles installed the same agent at the same time. Multiple challenges must be considered while implementing the vehicle agents. One is the power source that should be reliable and can be provided by the vehicle battery itself. In this project, the power source was a simple USB cable for testing purposes. Another challenge to consider is the GPS coordinates which might take some time to connect to satellites and start receiving the coordinates. However, the GPS module should be in an open environment with no obstacles to obtain the coordinates accurately, taking advantage of modern technologies using a combination of network connectivity through the GSM module and Bluetooth connectivity to increase location accuracy in the future.

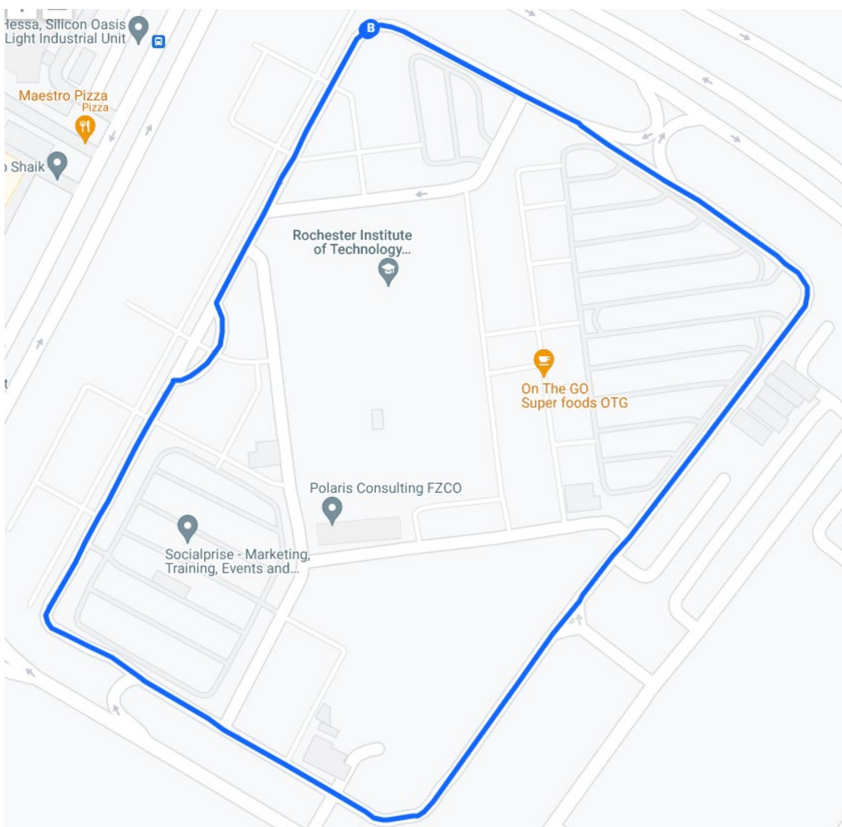

Figure 40 Real-Life Scenario Map

Chapter 5: Conclusion and Future Improvements

5.1 Conclusion

While concluding the entire study, it has successfully achieved the stated goals. To be more precise, the study has investigated various technologies that can be used in vehicle communication and will implement a smart traffic system. Additionally, the study has shown that with technological aspects, road accidents also can be diminished. However, the study has come across a system architecture that will help to develop the vehicle communication system. The added figures have helped to understand the components of the system architecture. The outcome of the infrastructure is impressive as the system is equipped with numerous latest technologies, such as a LiDAR sensor, OBD2 scanner, Camera module, GPS and GSM modules, and the Raspberry Pi Microprocessor, which all combine into the vehicle agent services. To be more precise, all these parts help to make a prototype that will support further infrastructure of the system architecture. Moreover, various other technologies are proposed to be used in the future to achieve a smart road transport management system, such as Cloud watch or the AWS service, IoT service of AWS, and location service to locate the vehicles, routes, indexes, etc. In the aspect of the AWS location service, the "Amazon Web services" has been set to be implemented in the future.

The study has also implemented the scenarios of making the prototype. However, it will help the readers to have a detailed outlook of the prototype. The elaborated steps will help readers to understand the needed components to develop smart technology for vehicle communication. To be more precise, it can be highlighted that while implementing the vehicle agent within the system, different types of sensors have been configured. It will help to read all the data related to the vehicle.

Moreover, this study has found that through communicating with the collected data, the "Road Transport Authority" can track and analyze the existing traffic congestion. Additionally, with the help of other systems or the equipment attached to the system, the authority can make further decisions to manage the traffic on the roads. It will help the authority to make the needed decisions within a minimum amount of time. However, as the entire system is based on the latest technologies, there is a probability of getting technical issues within the system that must be considered.

The study has highlighted a real-life scenario to show the implementation of the developed prototype as well. Additionally, the developed 'vehicle agent' has also been tested thoroughly. In terms of the implementation of the vehicle agent, it has been found that it has worked efficiently and has successfully tracked the needed locations. The installed camera module has successfully detected the street objects. However, while implementing the stated system, the study has come across several challenges, such as the power source within the vehicle being needed to keep the 'vehicle agent' in action as the power sources are generated from the batteries of the vehicles, so the majority of car owners do not want to use the power.

On the other hand, while using the GPS locator within the agent vehicle, sometimes it may receive different coordinates that may harm the entire system, and the entire traffic system can fall under considerable risk of inaccurate locations. The study has highlighted the fact that by developing a "Sonik GPS" system aligning with high-rated tracking hardware and software, the challenges can be diminished. Additionally, as most similar systems worldwide are based on the Wi-Fi system, multiple devices must be added to the system. The connectivity system, such as 4G or 3G, can help to have better connectivity within the vehicle agent.

Finally, this study went through a detailed implementation and analysis to help the Road Transport Authority develop a reliable road traffic management system that will contribute to smart city initiatives and reduce traffic congestion and road accidents in Dubai. But are these solutions and technologies enough to minimize or even vanish the whole congestion in the city? Or should other factors also be considered while implementing these solutions? These might be good points to start with for further research in the future.

5.2 Future Improvements

After analyzing the entire study, some recommendations or future improvements can be derived. Hence, the future improvements are listed below.

As the system infrastructure deals with a wide range of the latest technologies, it will be better to have skilled employees who efficiently manage technical glitches.

Before implementing the entire system into the traffic management system, it is essential to have a trial of the system as it will help to spot the forecasted risks of the system.

In addition to improving the system, the application service can be developed using a web Application Programming Interface (API) that includes the city map to view and manage the vehicle agents in the city, view road traffic and analyze it, as well as creating dashboards that will help the Road Transport Authority in visualizing the vehicle agents on all installed vehicles. However, due to time constraints, this project included only the vehicle agent, and application service is included in future improvements.

Regarding the Wi-Fi system or the GPS locator, it is essential to have the exact coordinates. Still, sometimes different coordinates take place within the system, which may cause the breakdown of the traffic management system, and even more, it can cause a further road accident. Hence, Wi-Fi technology should be developed, and other networking options should also be engaged within the infrastructure.

The developed system demands a real-time location, and it helps transmit the data related to the position and speed of the vehicle. In one aspect, it can help mitigate the risk factors of further road accidents, but false data transmission or the wrong real-time location may increase the chance of accidents on the roads more than anything else. Hence, the system's infrastructure should be upgraded with more options and backup plans (networks, hardware) to mitigate the risk factors.

Hence, the study needs to be added with the required data related to the mentioned factors. However, it has generated a chance to have further improvements.

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