Smart Cities V2I Cloud based Infrastructure using Road Side Units

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Abstract: Vehicles and city infrastructure can be interconnected through Road Side Units (RSUs) and On Board Units (OBUs) that utilize Radio-frequency identification (RFID) technology to send and receive information about various road conditions in real time. The objective of this work is to create and test a mesh network through Internet of Things (IoT) devices to emulate and test the RSUs capabilities. A vehicle-to-infrastructure (V2I) network is established through parent & child approach that rely on previously established infrastructure. The purpose for this design is to extend the reach of the system while limiting the amount of endpoint nodes needed. The mesh network is meant to target areas affected with road congestion. Using this information, the vehicles and users will be aware of traffic conditions on their routes in real time. Connected vehicles will be able to adjust their routes to experience more efficient commutes. The mesh network is capable of taking information from vehicles and transmitting it through the network until being uploaded to the cloud. In particular, the number of vehicles passing through an endpoint RSU within a certain time frame is collected and sent through the network, along with the location of the endpoint RSU. The parent node receives this information through a relay RSUs and uploads it to a cloud service where the data is collected and then analyzed through a data mining software. The software applies the k-means clustering algorithm to classify the traffic conditions of the road at a particular time. Results shows the capability of the algorithm to detect and classify the different traffic conditons.

1 INTRODUCTION

Recently Internet of Vehicles (IoV) is considered one of the most accelerating research araes. Investigation optimal communication and computing methods for vehcle connectivity is deemed essentail to create an IoV. Successful efforts is recognized in innovating Autonomous Vehicles (AV) include using On Board Units (OBUs) that can communicate wirelessly to assist AVs staying in the correct lane or during self-parking. To further innovation and efficiency, Road Side Units (RSU) can be implemented to assist vehicles by collecting data regarding various road conditions, and then use this data to reroute vehicles to alternative roads that decrease travel time. Additionally, the data collected will provide useful information for emergency services as they quickly respond to accidents and other hazards that appear on roads.

RSUs are designed to create more efficient routes and a much safer environment for fully autonomous vehicles on the road. The RSU communication happens in an ad-hoc network where the vehicles can communicate among one another, but the data exchange can be expanded with the use of the roadside units(Silva and Meira, 2016). In (Silva and Meira, 2015) the data is processed and translated into useful information and recommendations to assist the users of the transportation and transit authorities. The RSU will be combined with the communications from Vehicle Ad-hoc Network (VANETs) where the RSUs disperse messages at designated locations along the road network, and will expand on the types of information collected such as weather conditions, road work, the time, fluctuations of traffic, and so forth, which will lead to much more accurate coverage of data, and expand coverage as referenced in (Albouq and Fredericks, 2017; Lin and Rubin, 2017).

For this system to operate, the corresponding components need to be able to collect, track, and distribute information at high rates, and in large volumes. The studies in (Ansari et al., 2013; Santos et al., 2016) used a system consists of a microcontroller, GPS, Digital Short-Range Communication (DSRC) module, WIFI module, and several other components. The

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system is (Ferre et al., 2013) is used for charging stations, the system being implemented is altered to meet the demands of being on a road with live traffic. Radio frequency identification allows for transfer of specific data, and with the integration of sensors and microcontrollers along with the cloud provides the communication protocols, and service applications for an efficient network (Salahuddin et al., 2015).

While RSUs seem like a viable solution for most issues regarding VANETs and autonomous vehicles, they do come with their own sets concerns. As presented in (Ota et al., 2017), RSUs placement can have a huge influence in how efficient their energy consumption is as well as how many RSUs must be placed per area. With cost in mind, RSUs must be placed efficiently to obtain the best service for the money being spent. Fixing the energy consumption issue can be done in numerous ways, such as solar power which can be used as the main power source for the RSUs, as their placement will consist entirely of outdoor settings (Khezrian et al., 2015). Additionally, authors in (Mostofi et al., 2013) suggests a viable solution for energy consumption by proposing a ON/OFF sleep schedule for the RSUs wherein there are designated times at which less-used RSUs will be shut off. These RSU locations will be based on the frequency at which roads are used at certain times.

As (Silva and Meira, 2015) mentions, a combination of stationary RSUs combined with mobile data centers, which will be vehicles with on board units, creates a network that has a wide coverage range and the most diverse capabilities due to the variety of information that can be collected from the mobile units, as well as the available information from the stationary RSUs. The stationary devices can be installed on the side of the road or on a roadside pole and come equipped with storage, processors, and network capabilities that allow for the communication among vehicles with the use of DSRC.

With the support of VANETs, autonomous vehicles will be able to travel with uniform spacing between cars which will alleviate traffic jams and improve fuel efficiency. One issue with pure VANET systems is the amount of data that can be passed through, which causes this communication to be limited. So, with the support of RSUs, the amount of data being used can be increased which will provide a more accurate and more robust infrastructure.

A wireless mesh network is a communications network made up of nodes configured in a mesh topology. The network topology is an arrangement of how the system is communicating to one another. An ad-hoc network is a form of a mesh network that contains wireless nodes. These nodes can form a network that does not rely on fixed network infrastructure. Multiple studies discussed the differences between VANETs, MANETs, and Intelligent Transportation System (ITS) as sub-classes of an ad-hoc network. All of these networks and systems combine the telematics to the roads so that a system can maintain the goals for achieving better roadways which will create a safer road, environmental protection, efficiency, and benefit the economy (Sharmila and Shanthi, 2016).

The mesh ad-hoc network is designed with three types of nodes, each with a specific function. Gateways are devices that can connect beyond the mesh network and have access to the cloud. Repeaters are devices that are capable of forwarding data between endpoints in the mesh network. Endpoints are devices that are not capable of sending messages for other devices within the mesh network. These three types of nodes create the mesh network that is capable of transmitting data of the road conditions to the server via 5G (Lee, 2018; Kuo et al., 2013).

There are multiple types of ad-hoc networks that can be used to create a mesh network – mainly Wi-Fi direct, Bluetooth or ZigBee configurations. All have strengths and faults. Wi-Fi direct has superior range and data transmission rates. However, as ad-hoc network information cannot inherently be shared between two client systems and must instead only be shared to a host, it also cannot perform any node-hopping techniques to send information (Wibisono and Bayhaki, 2015; Ashritha M and Sridhar C S, 2015).

Road conditions are constantly changing in different areas, which cause back-ups, sudden speed changes, and other types of hindrances on the road. The study in (kumar Gupta and Khara, 2015) calls for a system that will obtain current location road conditions, which is very specific for obtaining proper road conditions. There are several techniques that can handle the network connection for a multi-hop data exchange between Vehicle to Infrastructure (V2I) and between Vehicle to Vehicle (V2V), which will build a much more secure communication system. Road Side Units are relay nodes that can connect the VANET nodes with the rest of the network, and make the RSUs a key component for applications that require more than one application in the VANET.

This work aims at proposing a method for V2C communication that rely on VANET. The RSUs in the VANET will communicate information to one another so the data can quickly transfer to each repeater, which will then transmit the data to an endpoint. This endpoint will upload data to a cloud from which information will be dispersed to vehicles on the road. Using this method, the data collected will be readily available for vehicles to receive miles away from the origin destination. This will be possible through a node-hopping method of information transfer, where a node will use its neighboring nodes as relay points to send the data to a specific node.

Using strategic placement, the RSU can be optimized for ideal coverage with minimal RSU deployment, and cover cities as well as suburban areas. Adhoc networks do not rely on previous infrastructure, thus can decrease expenses required for RSUs to act as a gateway. The gateways receives information from various nodes and is the only component capable of conveying data to the cloud. The repeater is capable of only receiving and exporting data from other repeaters or a gateway, which will expand the range of communications. With proper placement techniques, data will be transferred from one RSU node to the next, quickly providing seamless information to the gateways in the mesh network.

Radio Frequency Identification (RFID) will be used to collect high volumes of data from vehicles on the road. The vehicles will have an OBU that contains a RFID reader and RFID tag to transmit and receive data. The RSU will be equipped with the same technologies to create a two-way data transfer system. With this dual transfer setup, cars will receive up-to-date information about the roads they travel on, and RSUs can receive up-to-date information from vehicles that have already passed. This method may also be used to update vehicles with speed limit information as well as other localization data or obstructions that may be located within the proximity of the RSU.

The information on various road conditions collected from this network will be sent to a parent unit that is connected to a cloud with use of a 5G network. The RSU that contains 5G capabilities is referenced as a parent unit, and only parents are connected via 5G and have the capabilities of collecting data from, and sending data to, the cloud server. The server will be used to store the data it has collected, which will then be distributed to the RSUs and transferred to the vehicles on the road. The information can modify vehicle routes and let the vehicles be aware of other any hindering obstructions on their routes.

2 SYSTEM ARCHITECTURE

Vehicle to Cloud (V2C) connectivity requires different forms of communication and this is where the architecture of the cloud comes into play. It is important to remember that when using for example a 5G network to connect to the cloud, three different types of communication among the vehicles and infrastructure can be created. These three types of communications are: vehicle-to-roadside unit (V2R), vehicle-to-vehicle (V2V), and vehicle to infrastructure (V2I). These components allow for edge and core cloud layers to be created, which means it can support data collection and exchanging, fully mining and utilization of collected data, and using various real-time efficient and secure applications. Reliable and on-demand vehicular data services and applications can be implemented in the cloud. Furthermore, in these cloud core and edge layers exists the permanent and temporary cloud computaional resources. In the core cloud there are temprory computing resources organized and made available to provide traffic managament and analysis as required. In the edge cloud, storage and communication resources of vehicles and road-side units are implemented to extend the core cloud and provide capabilities of storage and cloud computation.

Additionaly, there are security issues that do arise with this 5G cloud connectivity and IoT devices. One of the main issues is the security and privacy preservation of collected data from the VANET. This mainly has to do with the types of data and information that are being passed and collected in the cloud. This is a big worry for a lot of users when it comes to storing information into the cloud because information breaching is very common. It is recommended to incorporate proper security solution with the proposed vehicular to cloud platform to ensure security and privacy.

Vehicular cloud computing allow for higher volumes of data to be transmitted and collected in the cloud. With 5G become readily available, there will be support for various connectivity and significantly faster transmission with 5G communications. A V2C platform will be enabled to provide more reasonable and realistic services with the support of a 5G network. A computational infrastructure must be connected with a the vehicle grid that contains RSUs where it serves the purpose for creating a more efficient vehicle grid. Furthermore, the vehicle network is referred to as VANET where vehicles have OBUs installed and also roads are equipped with RSUs.

The V2C is capable of contributing in several different ways since it stores data of current road conditions. The vehicles can be interconnected to the cloud through the OBUs and the RSUs act as gateways to send the data to the cloud. V2C will primarily hold safety and also non-safety-related data that will be transmitted to vehicles for increasing road efficiency. There are three methods for disseminating this information to vehicles, one through the VANET using V2C communication, or using Vehicle to Vehicle

(V2V) communicaion, or by communication between RSUs . These methods are all supported for exchanging data in a modern transportation system according to the distances the systems can reach.

2.1 System Design

The overall design of the system for developing a wireless mesh network between nodes to collect the data and transport it into three layers of communication is shown in 1. These layers will be comprised of several devices and modules that will create a network. Within this network, information about traffic from vehicles will be communicated to a cloud service where data will be analyzed and sorted into categories that describe various road conditions

2.2 Parent Nodes

The Raspberry Pi acts as the gateway, which will make it the only component of the entire system that is able to receive data, send data, and upload data to the cloud. The model being used is the Raspberry Pi Model 3B, which was chosen since Bluetooth capabilities are preinstalled and will not require extra modules to transmit the data along the network. Additionally, this model Raspberry Pi also contains the ability to be connected to Wi-Fi which is ideal for testing since it can upload data at a faster rate. The Raspberry Pi does have an additional 3G module that can connect the Raspberry Pi to the server without the use of Wi-Fi. The Raspberry Pi contains Python code that allows the transmission of data from the Arduino, and then the data collected will be saved as a CSV file and then uploaded to the set server that will identify patterns in traffic conditions.

2.3 Repeater Nodes

The Arduino Uno connected with two Bluetooth modules creates the repeater portion of the system. It does so by receiving data through one of the Bluetooth modules then proceeding to process and continue sending the data so that it may be received by the gateway in a readable format. The Arduino completes this process by first seeking an incoming message from the Endpoint via the HC-05, then uses the second Bluetooth module to relay the information to the Gateway.

2.4 Endpoint Nodes

The endpoint Arduino Uno is the middle-point between the “vehicle” and the Repeater Arduino Uno.

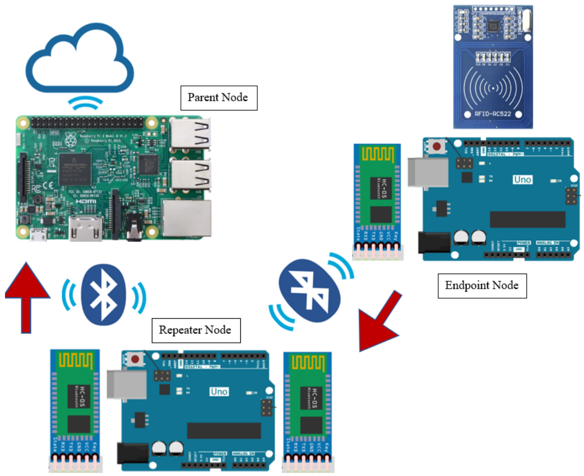

Figure 1: System Design.

It is the first interaction between a vehicle and the system itself. The endpoint Arduino is in charge of collecting the data from the vehicles. The method for this data collection involves the use of RFID via a MFRC522 RFID Reader module added to the endpoint Arduino operating at a frequency of 13.56 MHz. Radio-Frequency Identification allows a seamless, low-cost, and efficient way of transmitting data from the vehicles to the system. The endpoint Arduino collects the data, processes it, and then transmits that data and information to the Repeater Arduino. The method of transmitting this data is accomplished through Bluetooth, via a Bluetooth module added to the Repeater Arduino. The program that the Repeater Arduino uses to collect the data, process it, and transmit was developed using the Arduino IDE with the Arduino Uno and MFRC522 libraries. The Endpoint Arduino along with the Repeater Arduino have the capacity to be battery-powered, allowing them to have their own independent power source.

2.5 Cloud Service

The cloud service being used is called ThingSpeak. ThingSpeak is an Internet of Things (IoT) provider that will allow the storing of data to be possible through the internet. With ThingSpeak, it is possible for one to send data through a private cloud, analyze the collection data, and create graphs using MATLAB and essentially act on the data as well. Utilizing this service, a channel will be created to collect all the data and effectively display the amount of data being collected at different traffic conditions. This data will be stored in the cloud and then saved as a CSV file, which will then store and graph the data using a channel ID on ThingSpeak. On ThingSpeak, there are two separate fields used to represent that number of cars

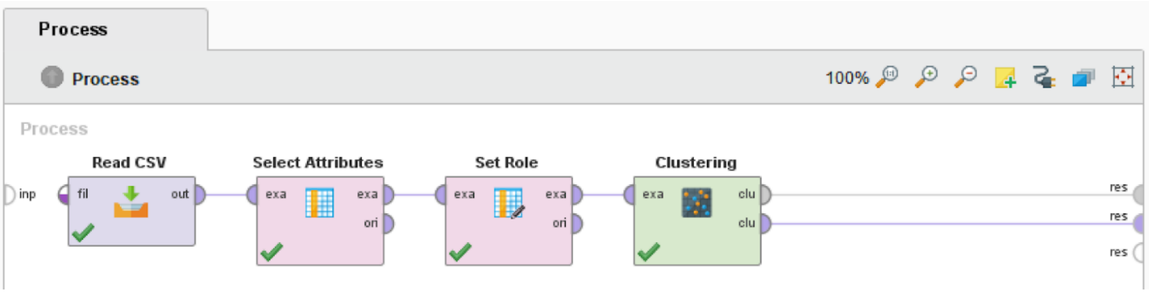

Figure 2: K-means Block Diagram.

passed and the location that the vehicle is at. From here, the data will be classified in real time showing the progression of traffic as well as the differentiation of location.

2.6 System Data Analysis

RapidMiner is a data service software that will be used to facilitate organizing, sorting and analyzing the data received from the vehicles. The software is capable of providing a machine learning and deep learning environment for our data to help discover meaningful patterns in the data. The project will use RapidMiner to demonstrate how the system can be beneficial once implemented. More specifically, in this program, the k-means clustering algorithm is used to cluster the data created. These clusters are based off of similarities between the data points uploaded from the CSV file. The clusters will serve as classifications to our three traffic scenarios, low traffic, medium traffic and high traffic.

In order to utilize the k-means algorithm in RapidMiner, the block operators as shown in 2 were used to allow the data from the CSV file to be imported. The select attributes operator's purpose is to only select the subset of attributes needed and exclude the other data, so in this case, the entry ID number will be excluded. The set role block allows the user to select the data in the number of vehicles passing and make it target role. Lastly, the clustering operator uses the k-means algorithm to classify a set of k-clusters based on the similarity of the data.

K-means operates by taking n observations of information and creates k-sets by which to divide the information into. The algorithm that determines a mean for each data set and uses that mean along with the rest of the points present within the set to determine the actual centroid of the data set. The algorithm finally uses the new centroid to determine if more data points from the original set belong in its respective cluster based on its variance from the centroid and calculate it as follows equation 1:

$$arg_s \, min \sum_{i=1}^{k} \sum_{X \varepsilon S_i} \|X - \mu_i\| = arg_s \, min \sum_{i=1}^{k} |S_i| \, var \, S_i \quad (1)$$

In this equation, S_i is the respective set that the cluster is being determined for and μ_i is the mean of the points within S_i as well.

3 SYSTEM CONFIGURATION

An important aspect of this project is being able to obtain real-time and accurate data. The objective when it comes to collecting data focuses on specific parameters. These parameters are localization, number of cars passing, and a real time timestamp. With these parameters, we hope to be able to create a RSU algorithm which will allow for the traffic congestion to be improved thoroughly. The sampling of data will all revolve around a simulation which we will create ourselves. It is difficult to test this out in a real-life scenario because we do not have the resources for a large-scale type of testing to be performed. The main study variables will be the successful detection rate of the RFID tags with the RFID readers. To maximize the detection rate as much as possible, it is vital that the readers on the side of the road are able to capture the data from the vehicles RFID tags consistently, especially considering the speed of the vehicles as they pass the readers. All data will be captured from the vehicles and successfully passed through road-side units and eventually to the cloud. The other detection rate we will be observing is the transfer of data from the road-side units to the vehicles' on-board RFID readers. A successful transfer of data between the vehicle and the reader will include data such as the number of vehicles passing by the RSU in order to determine the volume of traffic. All of this data will be uploaded to the cloud through the parent RSUs. This will allow the classification of traffic scenarios. Table1 shows the test bed specifications and Fig. 3 shows the used hardware.

The Raspberry Pi communicate with the Arduinos

Table 1: Test bed specifications.

Component	Description
Arduino Uno	Data Gathering Child Nodes and data repeater nodes
HC-05 Bluetooth Module	“AD-HOC” Network (connection in place for Wi-Fi option)
RFID-RC522	RFID Reader/Writer Components
Raspberry Pi 3 B+	Network Connected Parent Node
Raspberry Pi 3G-4G/LTE Base Shield V2	
Quectel UC20-G Mini PCle 3G Module	Provides 3G/4G capabilities for Raspberry Pi
LTE-G-086 Cellular Miniature PCB Antenna	

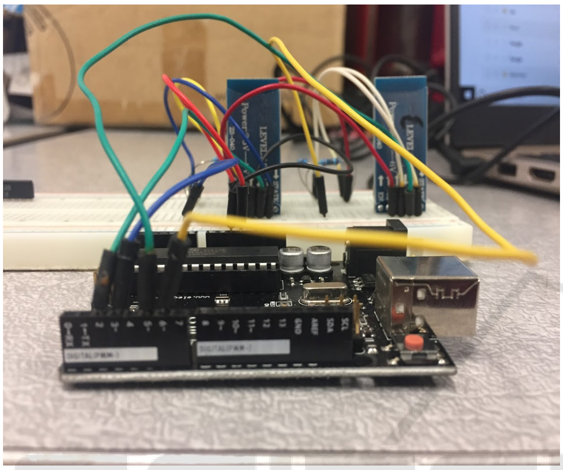

Figure 3: System Footprint.

to receive the data collected by them, and process/store the data to a cloud service using wireless and 4G communication. The Arduinos will work in tandem to collect and transmit the data received from the vehicles through the use of RFID and Bluetooth communication. The Arduinos will then pass the data along to the Raspberry Pi/Cloud network. The use of an mPCI-E Base Shield and a UC20-G became necessary as it will allow for 4G netwrok. Furthermore, this connection is being made through the use of a sim-card that is connected to the service provider and ThingSpeak service is used to collect all the incoming data through various channels that collects specific data and make a visual representation of the data. This data is then being ran in RapidMiner which will create K-mean map that shows a cluster of the data.

For relaying purpose two Arduinos are connected, the goal was to connect the Endpoint Arduino, which will receive the data from the vehicles, to the Repeater Arduino, which will pass the data on to the Raspberry Pi and continue along the mesh network. The method of communication between the two Arduinos was Bluetooth, using a HC-05 Bluetooth Module attached to each Arduino. The Endpoint Arduino had both the RFID RC522 module and the Bluetooth module attached to it through its digital ports. The Repeater Arduino had two HC-05 Bluetooth modules attached to it through its digital ports. The Endpoint Arduino was programed to keep track of the number of vehicles that pass through the RFID scanner/simulated road in a specified amount of time. In order to simulate data being collected from multiple sources, we configured the code to switch between two identifiers to mimic multiple endpoints so that we will have another parameter by which to sort the data from. This data was sent to the Repeater Arduino through Bluetooth to process and then transmit it to the Raspberry Pi. The data for the number of vehicles passing by was desired in order to analyze and determine what the traffic congestion is on that certain route.

Three traffic scenario (low, medium, high) were developed for testing purposes, the road being tested will either have low traffic if the range of vehicles passed was between 1-15, medium traffic from 16-30 vehicles, and high traffic from 31-50 vehicles. The data send and receive is done using the RFID Arduino by transmitting that data over to the Raspberry Pi. When configuring the Raspberry Pi 3 to be compatible with the rest of the system, there were numerous factors to ensure that it can connect to the Repeater node. The first was ensuring that the native baud rate of the Raspberry Pi matched the HC-05 that it was to be paired with on the Arduino. This required several commands to be written in the terminal to connect the HC-05. Once paired the HC-05 was configured to match the same baud rate of 115200, this required forcing the HC-05 into its AT command mode where the UART number can be configured. This baud rate was chosen due to its speed as well as the ease to configure the HC-05 as opposed to the Raspberry Pi. We then used a script that can take in the data and display it on a common window. Once the entire system was successfully connected, all that remained was processing the data on the Raspberry Pi to prepare it for use on RapidMiner. RapidMiner is a data collection software with a clustering algorithm called k-Means. This algorithm will take the data collected from the cars and distribute it so it can be classified as high traffic, medium traffic, and low traffic.

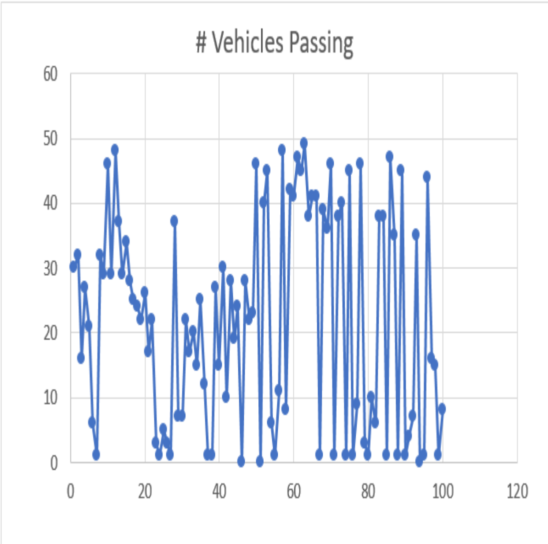

Figure 4: Number of vehicles Passing/Scan.

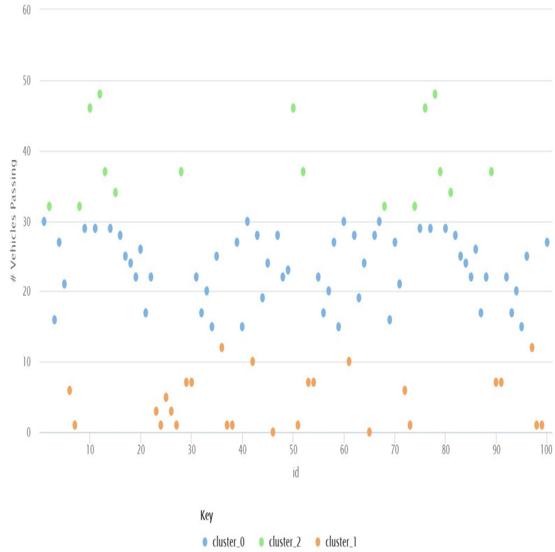

Figure 5: Collected Traffic conditions by RSU.

4 SIMULATION AND RESULTS

The goal of simulating the results was to have a random number of passes for each 15 seconds with an allowed maximum of 50 cars passing at a time as shown in Fig.4. As progress continued on collecting data, the group decided to find the limits of the range of Bluetooth communication for the RSUs. It was an interesting characteristic to investigate, because the most efficient way for cities to implement a system similar to ours will be to separate each child RSU as far as possible in order to minimize the amount needed. The group moved one RSU farther from another that it was communicating with, until the pair lost connection to each other. The group found the distance to be 78 feet before the two RSUs can not send information to each other. This was a considerable distance and surpassed initial speculations. The design of the system was made with the extremely limited budget in mind, so it was motivating to see the inexpensive Bluetooth modules work at such a distance. This range can increase by a very considerable amount for real-world applications as opposed to the small-scale model, with increased budget and access to better technology can extend the range of communication.

The design of the system was also efficient in transmitting the data we desired to send. Taking less than a second per data point to collect, we were able to collect approximately 100 points from which to base the rest of the project off of. The system was able to properly simulate multiple locations and send indicators for each; this data was also successfully processed by the parent node and placeholder locations were able to be created for the respective indicators. After modifying the incoming data, that system was also successful in uploading the data correctly to the cloud server, Thing Speak, with no loss of data. In Thing Speak, we were properly able to classify the data into two different fields, one showing the number of vehicles passing and the second being the location. The traffic conditions were classified as low traffic if there were 1-15 vehicles passing, medium traffic if there were 16-31 vehicles, and lastly high traffic if there are 32 vehicles or more passing. For testing purposes, there were 100 scans done. As presented below in Fig.5, the scanned traffic is focused on mainly medium and low traffic.

When comparing the centroid values in the Table 2, it can be seen that the k-means algorithm is working as intended. By separating the data into three partitions, the algorithm was able to determine a value that will become the center for each cluster, the centroid. Using the average of the set of data points as the centroid, the algorithm was able to determine roughly the same range for the traffic conditions that we had set prior to the experiment. The algorithm then set a new centroid based on the points gathered in each cluster which can be seen in Fig.5 One thing to note, however, is that we did set our traffic parameters to be roughly equal separations of our maximum traffic value of 50, so it is interesting to see that the centroids that were calculated created clusters that matched our classifications.

Table 2: Test-Bed Specifications.

Centroid Table for Fig.5			
Attribute	Cluster 0 (Low Traffic)	Cluster 1 (High Traffic)	Cluster 2 (Medium Traffic)
# Vehicles Passing	3.811	41.839	23.594

5 CONCLUSIONS

Through the use of IoT devices, we were able to create an ad-hoc mesh network using a cloud-based infrastructure from these Road Side Units. With this system designed, there are 3 specific nodes discussed – an endpoint node, repeater node, and a parent node. After each tag is scanned by the RFID reader, the endpoint node will collect 2 specific parameters, the location and the number of vehicles passed within a 15 second time range. The purpose of the repeater node is to receive the data via the first Bluetooth module and then relay that information to the parent node via the second Bluetooth module. Lastly, the purpose of the parent node is to act as a gateway by being able to receive, send, and upload the collected data into our cloud service provider, Thing Speak. With Thing Speak, all the collected data is uploaded to the cloud and can be exported as a CSV file. After this, Rapid Miner, a data mining service is used to effectively utilize the k-means clustering algorithm to display the collected data into 3 clusters to show low, medium and high traffic. With the final design, the system was able to cover 78 feet indoors between the endpoint and repeater RSUs.

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