Co-Deployment of DSRC Radio and Cellular Connected Vehicle Technology in Tuscaloosa, AL and Northport, AL

Dr. Hainen, Alex, University of Alabama, Tuscaloosa, AL, USA,
Mulligan, Bryan, Applied Information Inc., Suwanee, GA, USA
Deetlefs, Johannes, Applied Information Inc., Suwanee, GA, USA
Mulligan, Iain, Applied Information Inc., Suwanee, GA, USA
Ashley, Peter Applied Information Inc., Suwanee, GA, USA

Abstract
The University of Alabama, in conjunction with the Alabama Department of Transportation, deployed connected vehicle technology at 85 major intersections in Tuscaloosa, AL and Northport, AL. Both dedicated short-range communication (DSRC) radio and cellular (C-V2X) connected vehicle technologies were deployed and installed so that the effectiveness of the two technologies could be compared. A smartphone application was also deployed to showcase C-V2X technologies that do not require additional custom hardware. Several key results were identified. Cellular technology was much easier to connect and deploy widely, as the smartphone application used could be easily downloaded to any smartphone. DSRC radios were functional, but providing on-board units to the public was not possible. This showed the difficulty of widespread DSRC deployment past the pilot phase. Despite some concerns, the cellular technology was not shown to struggle with latency when communicating with the smartphone application. In practical terms, the latency between DSRC radios and cellular connected technology was approximately equivalent.

KEYWORDS: Connected Vehicles, C-V2X, DSRC

Introduction

Connected and autonomous vehicles (CAV) have the potential to greatly improve roadway safety (1,2). CAV technologies are being used to create greater communication between vehicles, infrastructure, cyclists, and even pedestrians. Key real-world applications for CAV technologies include emergency vehicle pre-emption, crash collision warnings, red-light running alerts, and many others (3). While there is general agreement that CAV systems will improve roadway safety, there are still many questions to address regarding this new technology. One of the most pressing debates in the smart mobility sphere is the implementation and the future of Dedicated Short Range Communication Radios (DSRC) versus Cellular-based connected technology.

For the past twenty years, DSRC was protected by the Federal Communications Commission on the 5.850-5.925 GHz band as the future of connected vehicles (CV) (4). DSRC radios provide point-to-point communications, allowing for near-instant communication between units (5). Recently, cellular-based technologies have gained favor in the transportation industry as an alternate communication platform. Proponents argue that, at the speed cellular technology currently moves, any potential latency in communication doesn't affect the practical implementation of CV applications. With the coming of high-speed 5G, point-to-point communication between vehicles and infrastructure will be available through cellular communication.

The purpose of this project was to create a real-world connected vehicle test lab in Alabama. The goal of these deployment efforts was to establish a flexible connected vehicle platform where safety and operational applications of the connected vehicle paradigm could be tested. Work on the system is still ongoing, and further evaluation of equipment is planned (6). Thus, this paper will cover the initial install and setup of the two different systems and compare the ease of deployment and the accessibility of the technology. Additionally, this paper will address the effectiveness of cellular technology in regards to latency periods and practical use. The paper will provide details about a live connected vehicle platform and how it is configured, interfaced, and used by both travellers and system operators.

Methods

Eighty-five intersections were identified for the initial instalment of equipment. Both DSRC and cellular Road Side Units (RSUs) were installed at each of these different intersections. This allowed for a "hybrid connected system" that supports cellular and DSRC packets at each intersection. The smartphone application, TravelSafely, was deployed as an On-Board Unit (OBU) for drivers in the area. This app was able to receive both cellular and DSRC information packets from the hybrid system. DSRC specific OBUs have yet to be configured and deployed on test vehicles.

RSU and OBU Equipment

Currently, traffic signal controllers are facilitating signal phase and timing (SPaT) information in a wide variety of ways across the industry. The Society of Automotive Engineers (SAE) has specification “J2735D: Dedicated Short Range Communications (DSRC) Message Set Dictionary” to standardize SPaT and other C-V2X communications. Since each controller and manufacturer is slightly different in execution of J2735D, some sanitization of the messages is required, particularly for the wide variety of DSRC radios. Most of the current generation DSRC radios have some on-board processor to communicate with the traffic signal controller. Aside from the DSRC approach, facilitating SPaT and basic safety message (BSM) information over cellular requires a very different approach.

In regards to cellular equipment, AI-500-085 Processor units (-085) were installed. This unit is pictured in Figure 1. The -085 processor is able to monitor both the traffic signal cabinet and communicate with the OBUs, such as the smartphone app, TravelSafely, that is being utilized in this project. This unit is plugged directly into the traffic cabinet and is connected to the central system cloud, Glance. This central system is detailed in the sub-section, “*Central Systems*”. Through the 4G LTE and the Cloud database, the unit is able to broadcast information to the traffic operations department managing the device, connected vehicles, and receive inputs from connected vehicles as well.

Figure 1:AI-500-085 Processor

With regards to DSRC communication for the project, the -085 processor also serves as the SPaT translator from the traffic signal controller to the DSRC radio. This was done as the ConnexUS Locomate Roadstar DSRC radios (Figure 2) installed were not directly compatible with the Siemens M60 advanced traffic controllers (ATC) used in this project. The -085 is able to translate the SPaT information to the connected radio, format the data into the standard J2735D protocol, and send messages to the OBUs in the network. This occurs vice versa in that the -085 also receives Basic Safety Messages (BSM) from OBUs and encodes them in J2735 format for the roadside units (RSUs). The physical equipment setup for this is demonstrated in Figure 3.

Figure 2: ConnexUS Locomate RoadStar

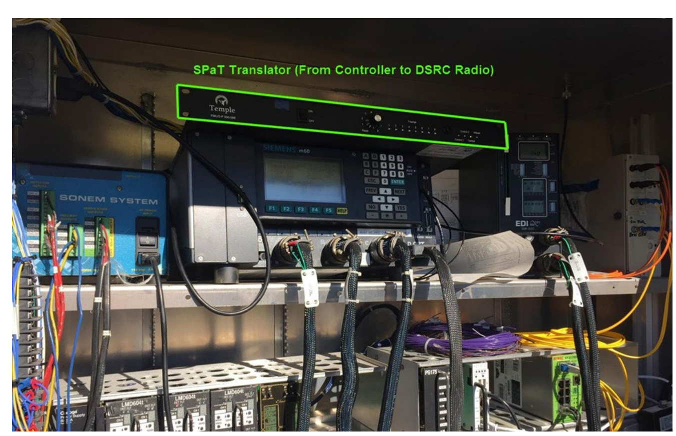

Figure 3: -085 as SPaT translator

The -085 processor is able to connect with both cellular and DSRC OBUs, the TravelSafely smartphone app, and the Lear ConnexUS Safety Human Machine Interface (HMI) smartphone app (an accessory application that has also been configured for future anticipated projects in this vehicle test lab). The -085 processor utilizes point-to-point communication and ethernet when working through DSRC communications. It is through ethernet that this unit is able to communicate to the central system and traffic operations.

Connected Vehicle Smartphone Application

As mentioned, the smartphone application being utilized in this project is TravelSafely. Its purpose is to act as an aftermarket application-based OBU for testing in this project. TravelSafely is a connected traveller system that allows for V2X communication, including vehicle-to-vehicle, vehicle-to-pedestrian, and even pedestrian-to-cyclist. The TravelSafely system works through both cellular and DSRC radio communication and processes whichever packet (either DSRC or cellular) comes in first. TravelSafely uses SPaT messages from the traffic signal controller, along with information packets from other connected vehicles, to provide users with “Alerts”. These are given to the driver though both visual cues and spoken messages. The application provides the following alerts and information for users:

- SPaT/MAP display of signal timing
- Red-light running at traffic signals
- “Get Ready for Green” alerts
- Bus/transit priority
- Emergency vehicle pre-emption
- Intelligent school beacons
- Direction of approaching emergency vehicles
- Motorist – Cyclist communication and alerts
- Motorist-Pedestrian communication and alerts
- Work zone warnings
- Curve warning/reduce speed warning
- Rear-end collision warning

An example of these alerts is exhibited in Figure 4. TravelSafely is a free smartphone application that is available for download on both Apple and Android devices. The app runs in the background. Meaning that users are still able to play music, navigate, or utilize other apps while using TravelSafely.

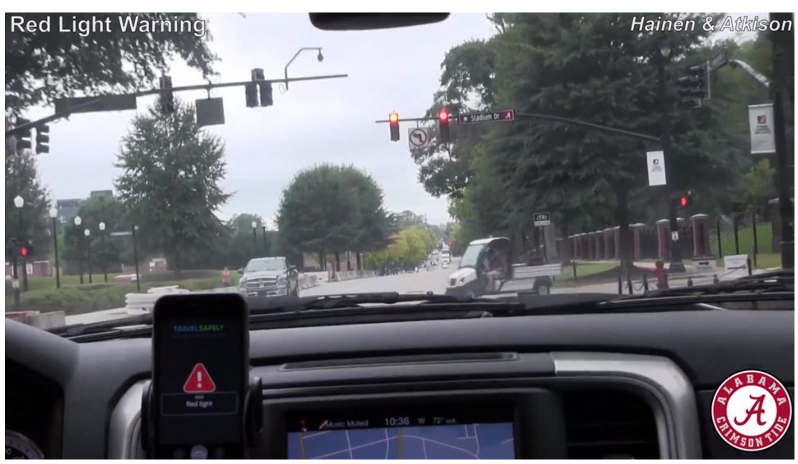

Figure 4: TravelSafely Alerts

Figure 5 below shows the Cloud CV architecture for TravelSafely. As seen in the diagram, TravelSafely directly receives inputs from the -085 units, connected, infrastructure, and other TravelSafely apps directly through cellular communication. Even as the information from the signal controller and the DSRC units aren’t directly compatible with TravelSafely, the -085 processor is able to convert the data into something readable for TravelSafely. In this way, TravelSafely is able to receive information from the controller and DSRC inputs.

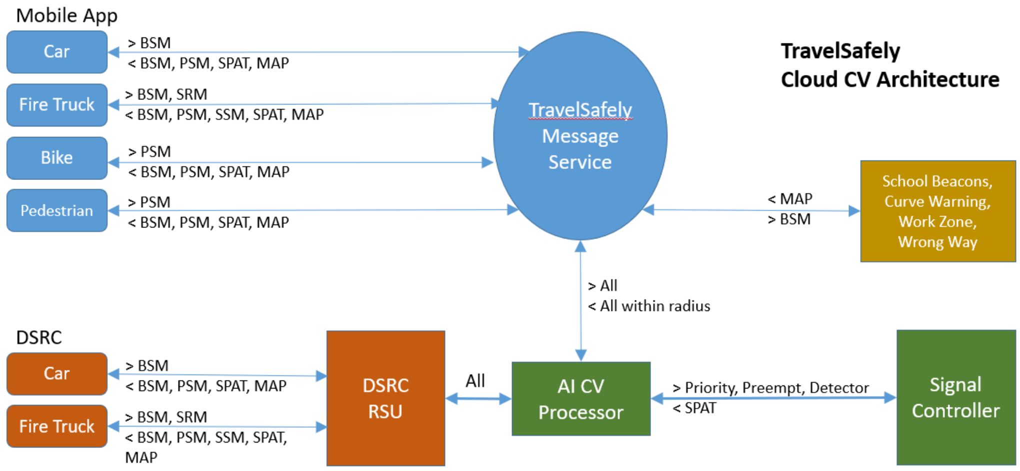

Figure 5: TravelSafely Message Flow Architecture

Central Software

The central system governing the cellular, DSRC units, and TravelSafely is the Glance Smart City Supervisory platform (Glance). This system was chosen for this project as it allows for management of all the connected devices and functions as a platform to monitor all connected road activity as well, including the tracking of dedicated connected vehicles, such as emergency vehicles equipped with OBUs. Glance provides an overview of the status of all connected traffic signal cabinets and components. The system provides a graphical map view to showcase the locations of all devices and the status of the intersection cabinets. Tuscaloosa's connected vehicle map on Glance can be seen in Figure 6.

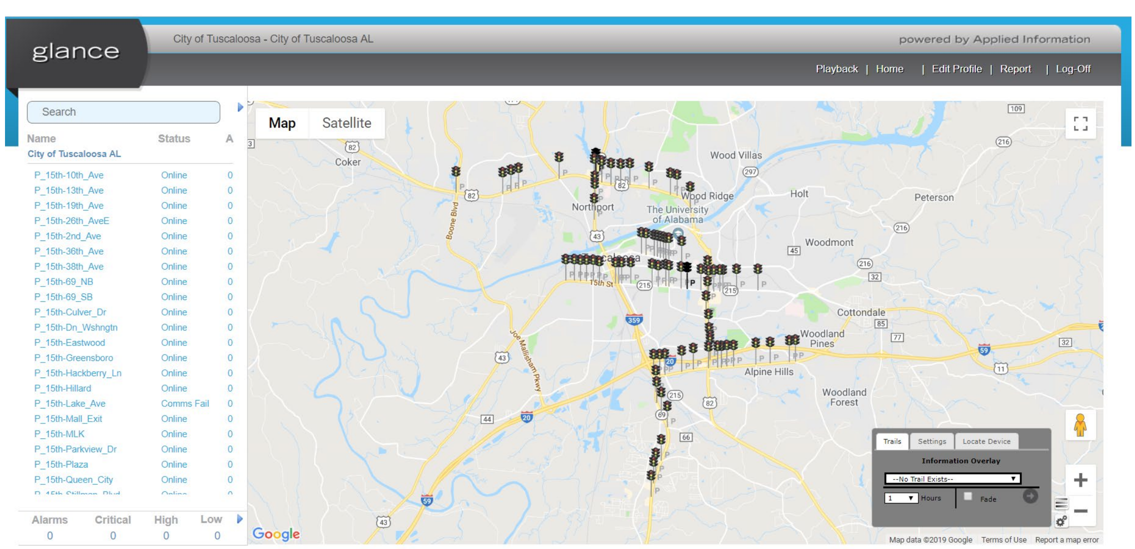

Figure 6: Glance connected vehicle map of Tuscaloosa, AL

The platform has the ability to provide in-depth information about each device connected to it. This information includes specific details such as power status, current alarms, device status, and more. All of the information received from the cellular and DSRC units can be viewed remotely, and Glance requires no additional software or equipment to manage the system.

As the system is currently configured, information flows from the traffic signals to the SPaT processor and then to the OBU and smartphone applications. This information is sent directly to TravelSafely via cellular communications The Glance RSU-Processor can also send the connected vehicle messages over Ethernet in J2735 format to the DSRC RSUs and to DSRC OBUs. A diagram showcasing the overall connectivity of the system can be seen in Figure 7.

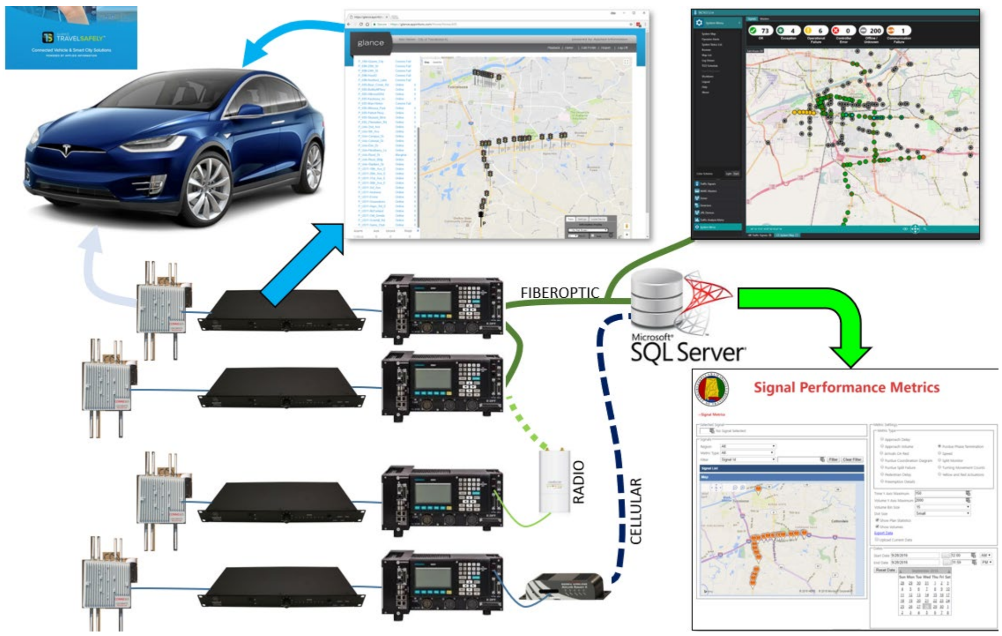

Figure 7: System Architecture

Other Equipment Used

One other smartphone application has been configured for this project. The Lear ConnexUS Safety HMI is an application that allows the wireless exchange of data among vehicles traveling in the same vicinity. The app allows vehicles on the roadway, including automobiles, trucks, and transit vehicles, to communicate with each other and with RSUs along the roadside. The app is downloadable for free on Android devices, but it does require an OBU in the user's vehicle to interface with other RSUs and OBUs in other vehicles. While preliminary lab testing of the RSU is underway, this app has yet to be fully integrated into the overall project. The app provides the following information for users:

- Vehicle-to-infrastructure communication
- Work zone warning
- Forward collision warning
- Situational awareness
- Distressed vehicle notification
- Crash ahead

An example of these alerts is demonstrated in the figure below:

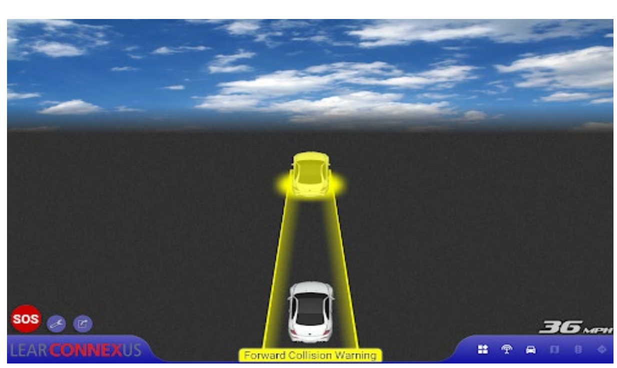

Figure 8: Lear ConnexUS Safety HMI

Installation of Units

The AI-500-085 processor RSUs were installed into the traffic cabinets as per manufacturer's standard protocol. ConnexUS RSUs were installed onto the traffic pole overlooking the intersection. This position gives the unit line-of-sight needed to communicate with the OBUs. The DSRC RSUs were then connected to the cabinet via ethernet cable. As explained in the "*RSU and OBU*" section, the -085 unit acted as the translator unit for the DSRC radio to controller communication. The physical wiring reflected this structure as well.

Figure 9: DSRC Installation

Configuration of Units

Cellular units and TravelSafely map files were configured in the manufacturer's map configuration utility tool. This tool is compliant with J2735_201603. Input for this map configuration utility includes configuring approaches and lanes by drawing linear representations on a Google map image. Lanes are linked to phase data so that users get the correct information when they are approaching on a specific lane. Once configured these map files are saved at each intersection as well being saved on the project server or in the Glance cloud server where they would be available for use by the connected vehicle system. The RSU-Processor is connected to the server where the map files are stored and securely checks the status of the map files. Anytime the map file stored on the server is changed, the RSU-Processor securely retrieves the revised map file and stores it locally at the intersection.

Results

The initial deployment and operation have yielded several key findings thus far. First, in regards to installation, cellular technology was much easier to configure and install than the DSRC equipment. In terms of physical installation, the cellular units could be directly installed into the traffic cabinet with no overhead work. Meanwhile, the DSRC units needed to be placed on top of the traffic signal poles with the use of a bucket truck and light traffic control where required. Placing the DSRC RSUs on top of traffic poles also presents a greater opportunity for damage to occur to a unit (especially in signal pole "knock-downs"). Also, the DSRC RSU is more likely to be knocked down from high winds and/ or suffer storm damage due to its high position.

In terms of configuration, the cellular units have the ability to have their firmware updated via "Over-the-air" (OTA) updates. This allows each of the units to be updated remotely from the Glance cloud. Any necessary changes to the firmware can be made immediately, allowing for the system to be very adaptable and flexible. The DSRC units, however, are much slower to have their firmware updated. Updates must be done with the unit's manufacturer. The units do have WiFi connection capabilities, however updates occurring over WiFi tend to revert the units back to factory settings and promptly turn off the WiFi capabilities. The most reliable way to update the DSRC units is through direct ethernet connection and one must be physically at the pole to update the unit in this way. It should also be noted that DSRC OBUs have no option for OTA updates. These units must be brought to an office to be updated.

The Lear ConnexUS HMI DSRC radio app was functional. The app was able to display the DSRC radios and their status. However, no OBUs are currently present in the system. Thus, the application exists but has no one to use it. Additionally, for the app to work, an OBU must be connected to the app. Aftermarket OBUs cost upwards of $1,000 and usually require modification of the vehicle. Most cars don't come with OBUs installed, leaving aftermarket

OBUs the only option for most individuals to be able to access DSRC technology. This makes distribution of DSRC technology beyond pilot programs expensive and impractical.

With the cellular-based app, C-V2X technology is easy to distribute to the masses. Massive cellular networks exist and most people in America have a smartphone capable of using this technology today. Additionally, most automotive companies have promised to include 5G C-V2X communications in their upcoming cars. Meaning that C-V2X communications will come at no cost to the end user. Even if a vehicle doesn't have CV technology directly programmed into their car, apps like TravelSafely can easily be used to provide C-V2X communications.

The main justification for choosing DSRC technology over cellular is that DSRC communications have much lower latency than cellular communications (7). However, this project showed the 4G LTE communications had a latency period of less than 300 milliseconds. While this period is longer than the DSRC communications, this time difference in latency periods have very little difference in the applications tested with this platform. In the future, higher levels of automated driving (L3-L5) may require low-latency V2V communication, but this current technology has already shown much potential as a connected traveller platform that can be easily used by today's technology.

Discussion

The initial deployment of the hybrid cellular and DSRC technologies presented the researchers with some key initial findings. However, more testing of the real-world vehicle lab is needed to yield further results. Several additional projects are currently planned to test the capabilities of the system.

The first proposed application is freight pre-emption. This application would connect freight vehicles to the installed system to give the vehicles green lights. This proposed project is located along the US-82, where 26 connected signals are located, and it is to be done through cellular pre-emption. This application would be utilized only when there is a need, based on route schedule and/or route conditions. The hypothesized benefits of this project would include reduced travel time, enhanced travel time reliability, and increased safety for freight vehicles at intersections

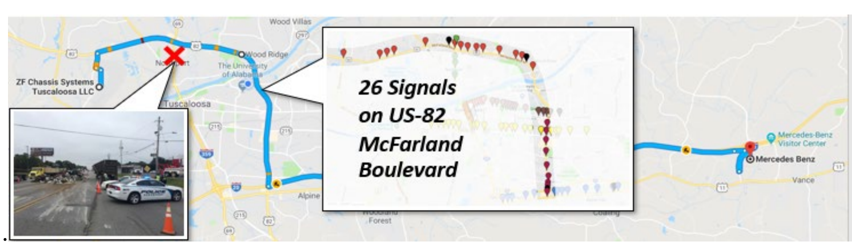

Figure 10: Proposed freight corridor project

Another proposed application is Signal BSM logic. The current system is transmitting SPaT information from the traffic controller to the Glance RSU processor, and then to the vehicle through OBUs. In short, the driver only *receives* output from the connected vehicle infrastructure. However, further proposed developments in this project would give the driver the ability to provide input into the system. This would work by having the smartphone applications broadcast a Basic Safety Message (BSM) to the RSU processor that would, in turn, the BSMs and vehicle trajectory information to the traffic controller. This information would allow the controller to better manage the flow of traffic/signal phases through enhanced controller logic and anticipated vehicle movements. Hypothesized expected benefits of this application are reduced delay times at intersections, increased safety at intersections for drivers, and a reduction in future detection maintenance.

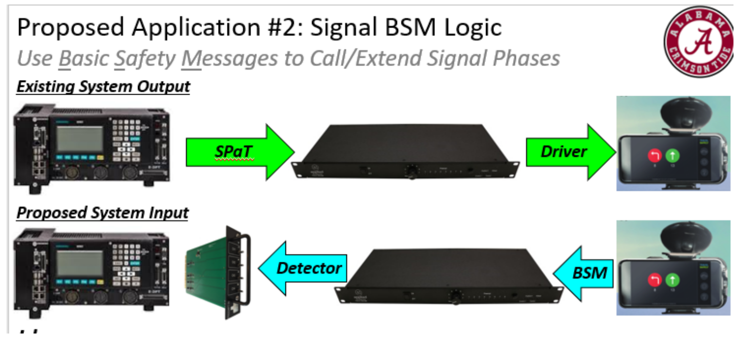

Figure 11: Proposed signal BSM logic

Conclusion

As connected vehicle communication platforms such as cellular, DSRC, and 5G continue to be debated in the industry, this paper shows a functioning pilot deployment of a hybrid cellular/DSRC connected vehicle system with potential for rapid distribution. This initial deployment of cellular and DSRC units at 85 intersections has shown several key results. The first was that cellular technology was easier to deploy. The second was that propagation of CV technology is much easier with cellular networks. Lastly, the cellular latency period with 4G LTE technology was not long enough to have any adverse practical effects. These are all preliminary results. The living lab in Tuscaloosa and Northport will provide more information about DSRC and cellular technology as the project continues to develop.

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