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# CV2X-PC5 Vehicle-Based Tolling Transaction System

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**ABSTRACT** With an increase in Toll roads in the United States, tolling agencies are looking for ways to simplify the process for themselves and their customers. Cellular Vehicle-to-everything (CV2X-PC5) Tolling offers a new approach to smart tolling system - it provides a significant opportunity to improve the usage of tolling systems for both customers and tolling agencies. Unlike existing tolling systems, the proposed CV2X-PC5 tolling system offers the tolling agencies a more dynamic and reliable tolling and road usage scheme, and the toll user - a transparent real-time information about tolling zones and receipts. In this paper, we present the feasibility test analysis and the various benefits of CV2X-PC5 vehicle based tolling transaction system that could bring great value to the vehicle driver and tolling agency utilizing this wireless communication technology. This paper details the test summaries for two-tolling use-cases: Fixed Rate Tolling and Managed Lane Tolling. Our results show that CV2X-PC5 vehicle based tolling transaction system will be an integral part of a future in connected transportation, by leveraging connected vehicle systems and data we can create better flowing, transparent, smart transaction system and improve the overall customer experience.

**INDEX TERMS** Cellular vehicle to everything (CV2X-PC5), connected and autonomous vehicles, tolling transaction system.

## I. INTRODUCTION

TOLLING and current problems associated with collection of payments and metering the use of road by commuters merits constant innovation given the cost and complexity involved in ensuring accurate transaction and collection. Traditional approach of tolling being a transaction between the drivers and tolling authorities where actors play different roles in establishing the validity of transaction while using manual cash/ credit lanes, transponders, RFID readers, Mobile apps etc. While each of these solutions have addressed some problems for toll collection, the current research focuses on "Vehicle as an Actor" and short-range communication being the tool or mechanism to accurately manage transactions of commuters while supporting different tolling authorities and their needs like dynamic pricing, need to reduce cost while maintaining transaction security for both the parties.

The hypothesis tested in this study "Vehicle to everything (PC5) tolling solution helps in creating a seamless, nationwide, reliable transaction for the commuter as well as different tolling authorities showing benefits that would address concerns of current solutions".

### A. PROBLEM STATEMENT

How might we amplify benefits to commuters and toll operators by design and proof of a Cellular Vehicle-to-everything approach that is consistent, smart and which can elude problems associated with current systems as well as pain points from human centric design standpoint.

*Current systems:*

- *Manual or Cash lanes:* Cash based lanes lead to traffic congestion which defeat the purpose of fast commute along with reconciliation and security issues for the tolling authorities while also leading to logistic infrastructure for currency.
- *RFID technology:* RFID systems don't resolve traffic congestion as each vehicle will need to scan a tag to a reader. Based on the quality of the system implemented RFID solutions can be easily disrupted by interference, collision etc.
- *Camera gantries:* Currently most of the tolling are based on the optical character recognition technology utilizing Cameras at gantries [1]. Camera gantry systems

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with pay by mail services are susceptible to poor identification of vehicles given weather and dust and contribute to high maintenance costs for tolling authorities. Malfunction of equipment lead to high volume of vehicles with unpaid tolling charges and discrepancies in collection of charges.

- *Transponders:* Transponders offer considerable advantages to many of technological issues provided in the earlier means of toll collection and payment [2]. However, they lead to number of human centric pain points such as not providing interoperability between regions, lack of transparency in charges, they do not provide confirmation of charges deducted or upfront information to the amount of charge and alternatives. Transponders have an elaborate account set up process and it requires a minimum balance which is not preferred by the user. Undetected transponder in vehicles continue to cause non- collected dues (also known as leakages) resulting in huge losses for agencies.
- *Tolling apps on mobile phones:* Tolling apps potentially solve to many of the above problems utilizing the phone's location services yet contribute to the human centric pain points such as ensuring the presence of your phone, linking the vehicle to the toll collection apps via the phone, ensuring location services are on for the tolling apps as well as the need for preloaded balance in accounts. The commuters continue to have security related issues, lack of transparency for charges and do not get real time updates of charges as well as confirmation of deduction of payment.

  *Human Centric problems:*
- *Leakages and Backend operations:* Leakages are referred to unpaid tolling charges from vehicles that are not captured well in Camera Gantries or RFID tags. Tolling operators need extensive collaboration with SOS (Secretary Of State) offices to track down license plates with unpaid dues which is a tedious activity and leads to additional costs.
- *Pre-Paid Account set up and Activation:* Tolling transponders and mobile operators require set up of pre-paid accounts with minimum balances to enable automatic deductions. This can be a pain point for Commuters as it locks up balance in accounts and does not provide transparency of current balance.
- *Lack of transparency, Visual confirmation, and notification of charges upfront:* Commuters often have to deal with each pay point as they commute and do not have a means of knowing total charges for the route section they are about to take versus an alternative route. On deduction of payment, they do not have a visual or audio confirmation that the transaction went through at a particular gantry.
- *Tolling operators and operation:* Dynamic pricing and Automated Lane management are operations implemented by Tolling providers in congested cities to implement dynamic pricing to manage high volume of vehicles. All the above-mentioned systems do not counter the problem of leakages due to dynamic charges levied. Automated lane management is implemented to automatically manage and change HOV lanes. The above-mentioned technology choices do not offer solutions to these problems.
- *Interoperability:* The problem which none of the above-mentioned technologies address is interoperability or the ability to travel to any state / province with a paid roads within a country without purchasing multiple acceptable passes across regions (for example see literature on Interoperability with Other Authorities in [2]).

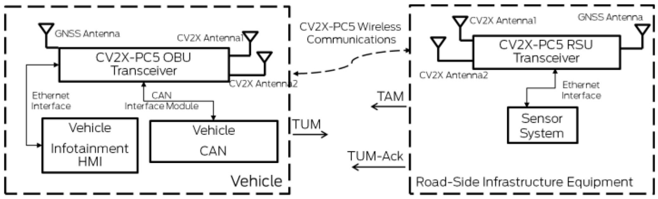


**FIGURE 1.** **CV2X-PC5 Tolling System Architecture.**

This paper covers the two aspects of the CV2X based tolling transaction system, first one being the vehicle user/customer's experience and how they interact with the interface and receive alerts and the next one is how CV2X-PC5 wireless technology (as referenced in the V2X-Based Fee Collection [3], [5]) can be leveraged for the tolling transactions and payment management system.

The rest of the paper is organized as follows. Section II describes the experimental setup and the overall system architecture with Tolling application on Vehicle and Road-Side-Unit. Followed by Section III with Results, Section IV with discussion and future work and Section V with Conclusion.

## II. THE EXPERIMENTAL SETUP AND SYSTEM ARCHITECTURE DESCRIPTION

### A. CV2X-PC5 TOLLING SYSTEM ARCHITECTURE

This section describes our overall system architecture that we have used for the CV2X-PC5 Tolling experimentation. Our experiment setup depicts the general CV2X-PC5 Tolling architecture from CV2X-PC5 Tolling Gantry and using SAE J3217 standard [3].

Fig. 1 shows the CV2X-PC5 Tolling system architecture used in the vehicle and the road-side-infrastructure.

- The Vehicle prototype system consists of the after-market CV2X-PC5 On-Board-Unit (OBU) with GNSS and CV2X-Antennas, Ethernet Switch, In-Vehicle Infotainment HMI, CAN Interface Module, Vehicular CAN Network.
- The Road-Side Infrastructure prototype system consists of the CV2X-PC5 Road-Side-Unit (RSU) Transceiver, Ethernet Switch, Sensor System.

The CV2X-PC5 OBU is used for

- CV2X-PC5 wireless communication of the V2X Tolling messages exchange between vehicle and road-side unit,

**FIGURE 2.** Showing Vehicle and Road-Side-Unit setup on Test Track.

**FIGURE 3.** Capture of Vehicle at TAM-Toll Zone on Test Track.

- The GNSS and CV2X-Antennas are installed in the center of the roof of the test Vehicle with respect to the lateral and longitudinal alignment of the test Vehicle by considering the Vehicle Width and Length. The placement of the GNSS antenna is crucial for the Tolling Application Algorithm to alert the vehicle driver and exchange V2X Toll Air Interface messages.
- CV2X-PC5 Tolling application which provides alerts to the vehicle customer on the vehicle infotainment HMI using tolling application algorithm,
- Our CV2X Tolling application algorithm on OBU
  - Receives and transmits V2X tolling messages,
  - Decodes and encodes V2X tolling messages,
  - Processes lane-level localization algorithm of the vehicle with the help of V2X tolling messages, Vehicle CAN and Vehicle GNSS location,
  - Provides various tolling use-case alerts and tolling transaction alerts to the vehicle driver relating to the type of the V2X tolling messages.

The CV2X-PC5 RSU is used for

- CV2X-PC5 wireless communication of the V2X Tolling messages exchange between road-side unit and the vehicle,
- CV2X-PC5 tolling application which provides acknowledgment V2X Tolling message upon reception of the V2X Tolling message from the vehicle when crossing the Toll-Zone

When reading the rest of this section, readers can refer to Fig. 1 to see the V2X Tolling messages exchange and Tolling information display to the Vehicle customer between Vehicle and Road-Side-Infrastructure system modules.

Fig. 2 shows the setup of the CV2X-PC5 road-side-unit with sensor system on the test track. In general, the CV2X-PC5 road-side-unit would be installed at the Toll Gantry along with the traditional tolling infrastructure such as vehicle enforcement system (VES) cameras, illuminators, digital video audit system (DVAS), automated vehicle readers (AVI) and laser sensors.

Fig. 3 Shows the capturing of the Vehicle at the Toll Zone as advertisement in the TAM message when the vehicle is performing the Fixed Rate Toll use-case testing on the Test Track.

### B. V2X TOLLING USE-CASES

This section describes the two-tolling use-cases we have demonstrated throughout this paper:

*Fixed Rate Tolling:*

- Toll rates that are fixed at a flat rate that applies for multiple gantries or single gantry.

*Managed Lane Tolling:*

- Toll rates that may be set in advance by time of day and based on traffic volumes observed during the past week, month, or quarter that applies for multiple gantries or single gantry.
- Toll prices are set “dynamically” to manage demand within the Managed Lane toll.

### C. V2X TOLLING MESSAGES OVERVIEW

This section describes the over-view of the V2X Tolling messages and V2X Tolling messages defined for the Fixed Rate Tolling and Managed Lane Tolling use-cases of our experimental setup. The V2X Tolling messages used in this paper which are aligned with the messages as represented in the SAE J3217 standard [3], [4]:

- *Toll Advertisement Message (TAM):*
  - A message which includes the advertisement for tolling which contains the information about the toll zone geometry and toll charges for the respective toll-type.
- *Toll Usage Message (TUM):*
  - A message which includes the toll road usage by the vehicle for further toll transaction payment reconciliation and enforcement purpose.
- *Toll Usage Message Acknowledgement (TUM-Ack):*
  - A message which includes that the respective vehicle’s toll usage message has been received from message acknowledgement purpose.


**FIGURE 4.** Fixed Rate Toll Advertisement Message.

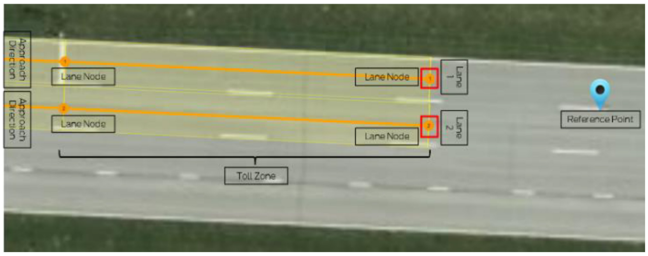


**FIGURE 5.** Toll Zone for Fixed Rate TAM.

**FIGURE 6.** Managed Lane Toll Advertisement Message.

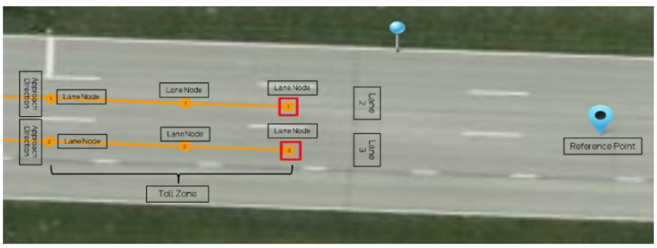


**FIGURE 7.** Toll Zone for Managed Lane TAM.

Fig. 4 explains about our TAM message defined for the experimental setup for the Fixed Rate Tolling use-case about the TAM Zone and Toll Zone for the TUM Trigger Zone and TUM-Ack reception zone.

Fig. 5 explains more about the Toll Zone of the Fixed Rate Toll Advertisement Message (TAM) which shows about the Approach direction, lane nodes, lane numbers with reference point information.

Fig. 6 explains about our TAM message defined for the experimental setup for the Managed Lane Tolling use-case about the TAM Zone and Toll Zone for the TUM Trigger Zone and TUM-Ack reception zone.

Fig. 7 explains more about the Toll Zone of the Managed Lane Toll Advertisement Message (TAM) which shows about the Approach direction, lane nodes, lane numbers with reference point information.

## III. RESULTS

In this section, we present the results observed from the perspective of the

- Tolling UX/UI alerts to vehicle customer of the Toll-Roads

**FIGURE 8.** Experiment Path Traversed on Test Track.

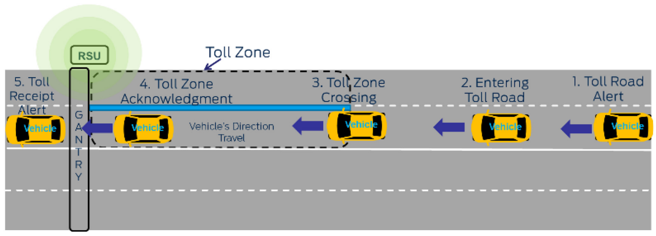


**FIGURE 9.** CV2X-PC5 key Tolling moments.


**FIGURE 10.** UX/UI Toll Alerts on Vehicle Infotainment HMI.

- Demonstrate how the CV2X-PC5 wireless communication could be utilized for CV2X-PC5 Vehicle Based Tolling Transaction System

Fig. 8 Shows the trajectory the vehicle traversed on the test track to test the Fixed Rate Tolling and Managed Lane Tolling from both UX/UI and CV2X-PC5 wireless communication perspective.

### *A. UX/UI TOLLING TRANSACTION ANALYSIS ON VEHICLE HMI INFOTAINMENT*

In Fig. 9 we have defined the key Tolling moments from vehicle-HMI perspective which could benefit the customer from CV2X-PC5 based tolling eco-system for testing on the test track for the Fixed Rate Tolling and Managed Lane Tolling use-cases.

Fig. 10 shows the locations of the UX/UI toll alerts displayed to the vehicle driver on Vehicle Infotainment HMI. Our Tolling application on the vehicle OBU determines when to show the tolling UX/UI alerts for different types of tolling use-cases.

We have conducted multiple iterations with varying speed of the vehicle from 5 MPH to 90 MPH for understanding of what, which and when to display the respective Toll UX/UI alerts to vehicle driver on the vehicle infotainment display while considering the safety aspects of driver and with minimal impact on driver distraction [as showed in the Fig. 10].

After regression testing of the Fixed Rate Tolling and Managed Lane Tolling use-case, we have identified typical Tolling key moments alerts can be showed to vehicle driver on vehicle infotainment HMI are as follows:

- *Toll Road Alert:*
  - The toll user receives an audio and visual notification on the vehicle infotainment HMI screen about an upcoming toll road with toll rate
  - Tolling Alert message is shown to the customer whenever the vehicle is approaching the vicinity of the enroute Toll Road for the Fixed Rate and Managed Lane Toll Use-Cases Scenarios.
- *Entering Toll Road:*
  - The audio and visual alerts on vehicle HMI shown to the vehicle driver when the vehicle is entering onto the Toll Road before the Gantry (Entry-Exit) for the Fixed Rate and Managed Lane Toll Use-Cases Scenarios.
- *Vehicle Toll Lane Identification:*
  - An alert displayed to the vehicle driver about which Toll Lane vehicle is automatically matched and driving before the Toll Gantry. This alert helps in display to vehicle driver which lane the vehicle matched for different lane based tolling use-cases such as Managed or Dynamic Lane Tolling [6].
- *Toll Usage Alert at Gantry:*
  - While on the toll road, the toll user receives an alert on the toll usage amount that the vehicle would be charged for the respective toll type usage. The toll type could be fixed rate tolling, managed lane tolling etc.
- *Toll Receipt Message:*
  - The toll user is presented with the receipt of the toll usage using the vehicle infotainment system with visual and audio alerts, in an efficient and non-distracting manner.
  - This is the toll receipt message showed to the vehicle driver whenever the vehicle receives the transaction status for the respective toll features (Fixed Rate, Managed Lane Toll) Toll usage of the vehicle.

### B. CV2X-PC5 TOLLING WIRELESS ANALYSIS FOR TOLL TRANSACTION

This section demonstrates the results with the Data Elements that we have used to prototype the Toll Transaction utilizing the CV2X-PC5 tolling wireless communication.

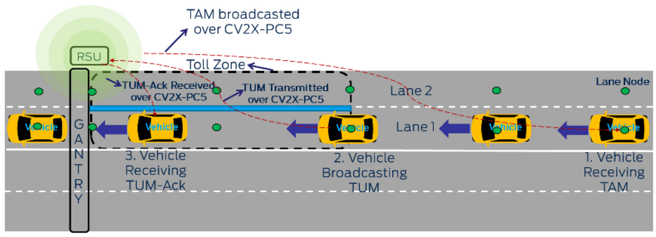


**FIGURE 11.** Tolling messages exchanged over CV2X-PC5.


**FIGURE 12.** V2X Tolling messages exchange on test track over CV2X-PC5.

Fig. 11 demonstrates about the Tolling messages exchange over CV2X-PC5, i.e., about the TAM, TUM and TUM-Ack with respect to the RSU at Toll-Gantry and the Vehicle.

Fig. 12 shows the vehicle's location on the test track utilizing the tolling application algorithm on the CV2X-OBU using the CV2X-PC5 wireless communication:

- when the TAM can be first received on the vehicle with respect to the distance from Road-Side-Unit
- when vehicle broadcasts the TUM for the respective toll type usage
- when vehicle receives the TUM-ACK for the respective broadcasted TUM

Our tests included multiple scenarios for the two-tolling use-cases along with straddling between the lanes for the managed lane toll use-case using our tolling application algorithm on the CV2X-OBU. We performed multiple regression tests with the vehicle speed factor varying from 5 MPH up-to 90 MPH in intervals of 5 MPH. We collected vehicle positioning logs, Tolling Application algorithm logs, Toll Usage Message Logs, Toll Usage Message Acknowledgement logs on the vehicle CV2X-OBU for up-to 150 experimental scenarios for both fixed rate toll and managed lane tolling use-case.

Table 1 shows the list of data elements from collected logs we have used for the toll transaction analysis over CV2X-PC5 wireless communication, even though logs have more data information.

Fig. 13 shows the KML figures of the GPS positioning of the TUM and TUM-Acks trigger points of the Tolling Application Algorithm on the Vehicle for varying speeds of the multiple tolling use-cases scenarios with respect to the Toll Zone Node-Points of the Toll Advertisement Message.

- *TUM Trigger:* The vehicle location which is a part of the TUM data has been plotted in Fig. 13.

**TABLE 1.** Data elements.

| *Name (Unit)* | *V2X Message Type* | *Description* |
|---|---|---|
| Time (StampDate.Hour.Min.Sec.MilliSec) | TUM | Time stamp in GNSS UTC time of 1 msec time accuracy |
| Temporary Identifier | TUM | Unique random identifier for each TUM message transaction |
| Message Count | TUM | To provide sequence number within stream of TUM messages |
| Vehicle Identifier | TUM | To identify the Vehicle ex, GUID |
| Latitude (deg) | TUM | Vehicle Position Geographic Latitude |
| Longitude (deg) | TUM | Vehicle Position Geographic Longitude |
| Elevation (meters) | TUM | Vehicle Position Geographic Altitude |
| Speed (m/sec) | TUM | Vehicle Speed |
| Heading (deg) | TUM | Vehicle Position Geographic Heading |
| Lane Number | TUM | Vehicle Map Matched to TAM Lane Number |
| Lane Position | TUM | Map Matched Straddling Position of Vehicle between the Two or within the Lane |
| Vehicle Type | TUM | Classification of Vehicle interms of overall size |
| Toll Charge ($) | TUM | Vehicle's toll road usage cost |
| Toll Service Provider Identifier | TUM | Unique identifier for identification of the Toll Service Provider |
| Toll Charger Identifier | TUM | Unique identifier of the Toll Charger as advertised in the TAM |
| Toll Point Identifier | TUM | Uni |
| Time Stamp (Date.Hour.Min.Sec.MilliSec) | TUM Ack | Time stamp in GNSS UTC time of 1 msec time accuracy |
| Message Count | TUM Ack | To provide sequence number within stream of TUM messages for corresponding TUM |
| Temporary Identifier | TUM Ack | Unique random identifier for each TUM message transaction for corresponding TUM |
| Vehicle Identifier | TUM Ack | To identify the Vehicle ex, GUID for corresponding TUM |
| Latitude (deg) | TUM Ack | Vehicle Position Geographic Latitude |
| Longitude (deg) | TUM Ack | Vehicle Position Geographic Longitude |
| Elevation (meters) | TUM Ack | Vehicle Position Geographic Altitude |
| Lane Number | TUM Ack | Vehicle Map Matched to TAM Lane Number for corresponding TUM |

**FIGURE 13.** Horizontal view of GPS KML Positioning Points of TUM and TUM-Ack Trigger.

This is the location where tolling application algorithm of CV2X-OBU on vehicle triggered the TUM that is to be sent to RSU via CV2X-PC5 wireless communication.

- *TUM-Ack Trigger:* The plots show the vehicle location, i.e., when vehicle receives the TUM-Ack data from RSU has been plotted in the Fig. 13. This is the TUM-Ack sent by RSU for the respective TUM sent by vehicle via CV2X-PC5 communication.

The performance of the CV2X-PC5 vehicle based Tolling Transaction can be evaluated by the Vehicle's proof of presence and exchanging the information with RSU of Gantry for transaction. To achieve this, utilizing our vehicular Tolling Algorithm application and low latency CV2X-PC5 wireless communication we show the GPS positioning plots of the following *toll-use-case scenarios* in Fig. 13, Fig. 14, Fig. 15


**FIGURE 14.** Vertical view of GPS KML Positioning Points of TUM and TUM-Ack Trigger.

which does show the capabilities and precision of the CV2X-PC5 tolling data with low latency communication and it's suitability to be used for toll transaction over CV2X-PC5 wireless communications:

- Test Scenario of Vehicle driving at 90 MPH in Lane-2 as advertised in the TAM message
- Test Scenario of Vehicle driving at 35 MPH in Lane-3 as advertised in the TAM message
- Test Scenario of Vehicle driving at 50 MPH in Lane-3 as advertised in the TAM message
- Test Scenario of Vehicle driving at 90 MPH in Lane-3 as advertised in the TAM message
- Test Scenario of Vehicle driving at 10 MPH while straddling Lane-2 and Lane-3; with 80% in Lane-2 and 20% in Lane-3
- Test Scenario of Vehicle driving at 30 MPH while straddling Lane-2 and Lane-3; with 80% in Lane-2 and 20% in Lane-3
- Test Scenario of Vehicle driving at 35 MPH while straddling Lane-2 and Lane-3; with 80% in Lane-2 and 20% in Lane-3

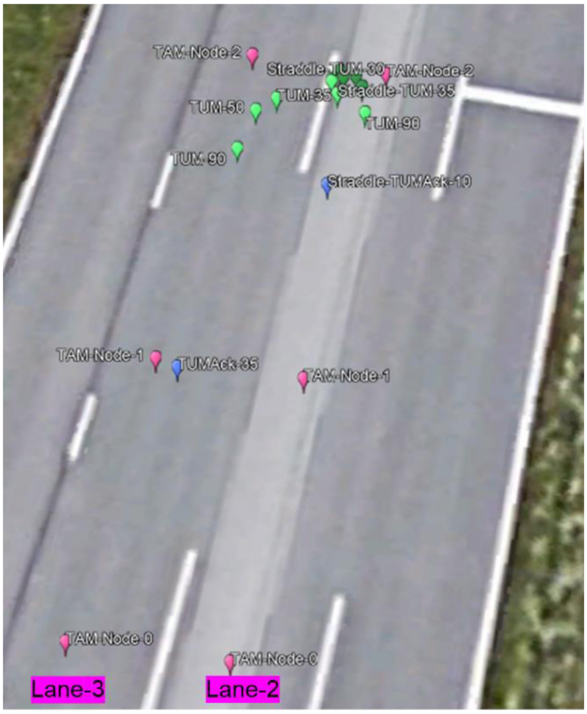


FIGURE 15. Another Closer View of GPS KML Positioning Points of TUM Trigger at Toll Zone.

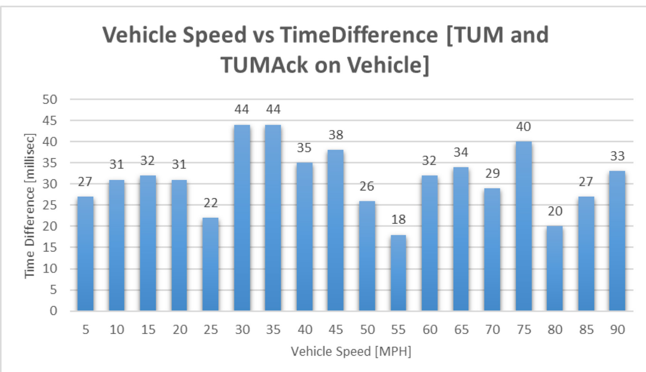


FIGURE 16. Plot of Vehicle Speed vs Time Difference of TUM and TUM-Ack on Vehicle.

- Test Scenario of Vehicle driving at 40 MPH while straddling Lane-2 and Lane-3; with 60% in Lane-2 and 40% in Lane-3
- Test Scenario of Vehicle driving at 45 MPH while straddling Lane-2 and Lane-3; with 80% in Lane-2 and 20% in Lane-3
- Test Scenario of Vehicle driving at 75 MPH while straddling Lane-2 and Lane-3; with 80% in Lane-2 and 20% in Lane-3
- Test Scenario of Vehicle driving at 90 MPH while straddling Lane-2 and Lane-3; with 80% in Lane-2 and 20% in Lane-3

In Fig. 16 we show the time difference in milliseconds at the Tolling Application layer utilizing the CV2X-PC5

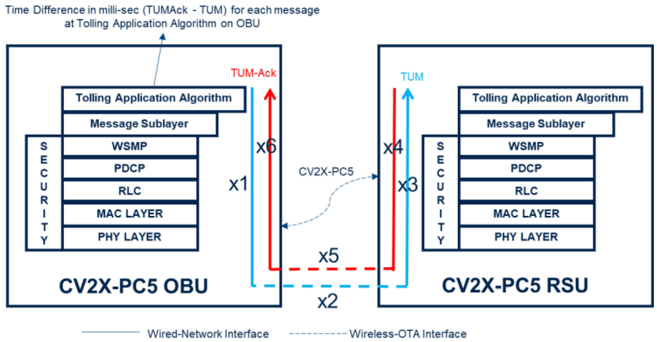


FIGURE 17. End to End System for Time Analysis.

wireless communications, i.e., the time difference in milliseconds it took between when the tolling application algorithm on CV2X-OBU broadcasted the TUM message at the Toll Zone to the RSU and the tolling application algorithm on CV2X-OBU received the acknowledgement of the respective broadcasted TUM message, i.e., TUM-Ack from the RSU for the multiple test scenarios of the test vehicle driving over the vehicle speed varying from 5 MPH to 90 MPH in the interval of 5 MPH between the test scenarios. The Time-variation includes the summation of x1, x2, x3, x4, x5, x6 processing and OTA time as shown in the Fig. 17.

## IV. DISCUSSION AND FUTURE WORK

### A. DISCUSSION

Vehicle-to-everything (V2X) tolling solution leverages short range CV2X-PC5 wireless communications and payment management services to create a single, convenient toll payment transaction for individual consumers and the tolling authorities.

Our paper demonstrates the two aspects of feasibility to achieve the CV2X vehicle based tolling transaction system from the vehicle driver UX/UI perspective and the CV2X-PC5 short range wireless communication benefits perspective.

We have also showed the feasibility aspects of how the vehicular based tolling solution could precisely locate itself at the Toll Zone using the TUM Trigger GPS positioning points, the data reliability using the TUM and TUM-Ack. The TUM data broadcasted by the vehicle contains the information required for the toll road usage. It relays information to the toll gantry so the toll charging authorities can process the toll transaction for the toll user.

This CV2X-PC5 tolling data provides more transparency of the toll transaction for the vehicle users and the toll authorities.

### B. FUTURE WORK

For our future work, we are planning to analyze how well the CV2X-PC5 vehicle based Tolling transaction system works in real-life driving at Toll Gantries:

- By considering the congestion scenario of CV2X-PC5 channel utilization when multiple CV2X-PC5 equipped vehicles are operational and communicating with RSUs at Toll Gantries.

- Utilizing the Tolling V2X messages with security [which includes signing, verification, encryption, and decryption]. The vehicle utilizing the TUM public key broadcasted as part of the TAM message and then Encrypts the TUM data and Signs prior sending OTA from Vehicle.
- Evaluate the system where the RSU is integrated into the current existing Toll Gantry system for comparison with current existing Tolling technologies (RFID, Camera etc.) of the Toll Usage Message Data
- Conduct user-clinics for understanding customer preference on the benefits or constraints of the multiple CV2X-PC5 based Tolling UX/UI alerts shown to the vehicle customer

## V. CONCLUSION

CV2X-PC5 technology can be used to simplify toll road systems and enhance consumer experience by interacting and utilizing various metered road systems. The long- and short-range communications provides direct a communication stream between vehicles, infrastructure, and pedestrians.

CV2X-PC5 Tolling also provides several strengths over current toll road systems: enhanced safety information dissemination like- accident information, travel advisory, roadblocks and weather information, enhanced tolling authority road management, reduced hardware overhead, user account consolidation, protocol standardization, and enhanced consumer experience when using tolling systems.

Based on the data shown above, lane level accuracy at the gantry may be achieved utilizing C-V2X technology. C-V2X Tolling can co-exist with the traditional tolling infrastructure such as vehicle enforcement system (VES) cameras, illuminators, digital video audit system (DVAS), automated vehicle readers (AVI) and laser sensors. While not a focus of the pilot, numerous studies have concluded 5.9 GHz based communications do not cause transmission interference with existing 915 MHz technologies.

The C-V2X tolling solution promotes significant benefits for toll roadway operators and customers alike. Benefits include, but are not limited to, national interoperability (SAE standard messaging), reduced toll transaction revenue leakage and overhead charges, flexible and dynamic pricing, and consolidating collection and enforcement. The concept furthers the convergence of tolling and ITS services through total corridor management. In parallel with tolling services, ITS safety and mobility use cases enable critical information dissemination for weather, accidents, travel advisory, roadblocks, and emergency and first responder vehicle alerts.

This report provides evidence of the feasibility of gantryless tolling which in the long run can result in significant reduction in infrastructure complexity, infrastructure investment and costly enforcement overhead services.

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