Utilization of Path History Data for the Extension of V2X Network Coverage

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***Abstract*—This paper demonstrates the usefulness of the PathHistory element in the SAE J2735 standard. A real-world test was conducted, utilizing the PathHistory element to display the track of a vehicle over 680 meters away, outside the range of the C-V2X (Cellular Vehicle to Everything) units. By utilizing the latitude and longitude offsets provided in the data, a reconstructed path of the vehicle was generated, beyond the view of the C-V2X RSU (Roadside Unit). This data element has the potential to expand the RSU coverage range far beyond what antennas were capable of. Several use cases were presented that allow for the extended coverage of RSU placements and the detection of crash elements on the road.**

Keywords*—*ITS, C-V2X, Traffic controller, Path History

I. Introduction

Intelligent Transportation Systems (ITS) and Vehicle-to-Everything (V2X) technologies have the potential to prevent up to 600,000 accidents annually [1]. According to the 5G Automotive Association (5GAA), achieving 100\% coverage of this V2X technology would be a costly endeavor, with an estimated cost of 12 billion USD by 2035 [2].

Much research has suggested minimizing the number of RSUs needed for V2X communication by placing them only at key intersections, utilizing genetic algorithms and SUMO traffic optimizations [3]. Research groups have also employed machine learning to reduce the number of required RSU placements [4]. Additionally, a study focused on optimal placements of RSUs considering cost and network maintenance [5]. A Voronoi-based algorithm that considered not only coverage but also radio performance was proposed [6]. In these previous studies, it was found that overall, sticking with main roads provided the best coverage.

This paper demonstrates the concept of extending RSU coverage by utilizing the J2735 Path History message element. The range of RSUs could be extended in the context of light timings and traffic management. A real-world test showcasing the ability to record up to 680 m of path history in each Basic Safety Message (BSM). Using the example of the real-world test, two example scenarios were created to show what use cases path history can be utilized in.

II. Real World Test of Path History

A. Equipment

The equipment used in the testing was the current generation C-V2X MK6C units from Cohda Wireless [8]. These units communicate using 3GPP Release 14. They are depicted in Figure 1. An OBU (On-Board Unit) is installed in a vehicle to record vehicle location and speed. The setup's location is illustrated in Figure 1(a). The RSU (Roadside Unit)is positioned along the Cyber Hall, as depicted in Figure 1(b). The RSU's placement is chosen such that when the vehicle rounds the corner of Randal Way and Kirkbride Lane, the vehicle's OBU comes within communication range of the RSU. The vehicle employed for the test is a Mercedes GLE 350, shown in Figure 1(b). The antenna for GPS and C-V2X is a MMXFG-5900

Fig. 1. Set up of real-world test; (a) OBU inside the test vehicle, (b) OBU and RSU antenna placement utilized in the test

B. Real World Testing

The ITS-equipped infrastructure follows the SAE J2735 standard [9], enabling communication between OBUs and RSUs within the vehicle network. The BSM framework can be set to transmit the "DF PathHistory" Data Frame, capturing up to 27 historical GPS positions of the journey. Offset points are generated from the current and historical positions, derived during message generation. This data, when sent to a RSU, allows back-calculation of the vehicle's historical position and time.

A real-world test of path history enables visualization of the past history data of vehicle location and speed. In our test, the test vehicle runs around the Cyber Hall located at The University of Alabama. A visual representation of the travel path is provided in Figure 2. The total travel distance covered is 1 km. The vehicle maintains a speed of 15 mph (24 km/h).The vehicle recorded messages in the BSM format throughout the test, which includes information about the speed, position, and path history of the vehicle. These messages are communicated with a stationary RSU, which in turn sends out BSMs. Line of sight (LOS) is established with the RSU at 640 m into the test and lost at 780 m into the test. Non line of sight (NLOS) is present in all other cases along the test.

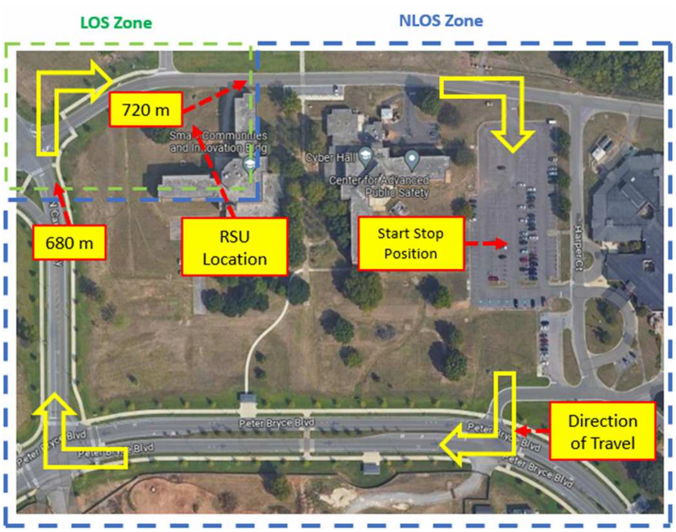

Fig. 2. Location and path of test vehicle

Once the test is completed the data was processed from the RSU and OBU. A point at 20 seconds into the test is taken and path history is analyzed. The snapshot of history displayed 7 path history points that are generated at that given moment. The data is entered into the mapping software GPSvisualizer shown in Figure 3. The vehicle travels southbound out of the parking lot and enters the street. This shows the first 7 path history points generated by the data frame. The path shows the previous 150 m of travel that happens before the current vehicle's position.

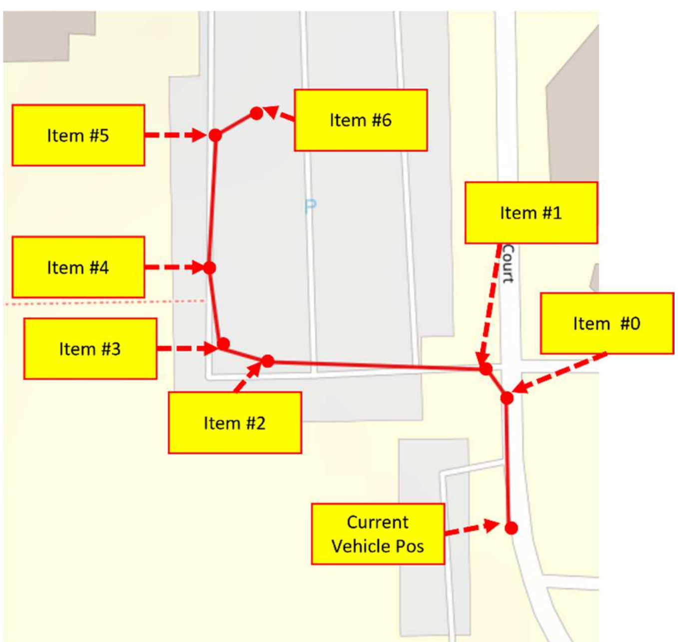

Fig. 3. Seven recorded path history points of data recorded by the test vehicles OBU

Every 2 to 5 seconds a data point is recorded into a path history element, a shift occurs into the buffer of location offsets. Shown in Figure 4 displays how the hand off occurs. Figure 4(a) and Figure 4(b) represent latitude and longitude as a function of time, respectively. The current position at a given time is shown as the black line. The OBU then determines when to record a new path point. This generally occurs every 2.5 to 5 seconds of driving. At 165 seconds into the drive, a location point is recorded and stored into location item 0. This will then shift every position down one item. That position was stored in the message until a new position was gathered.

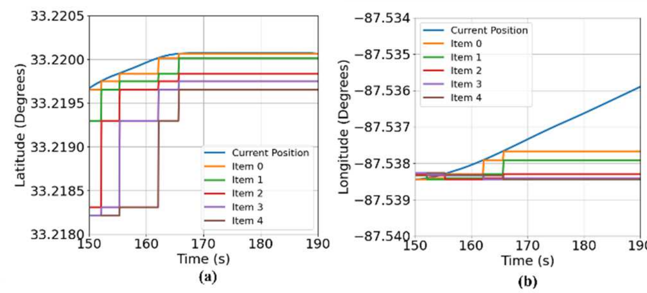

Fig. 4. Hand-off process of path history points; (a) Latitude, (b) Longitude

Using the raw offsets provided by the path history, the latitude and longitude were recorded in Figure 5 Figure 5(a) and Figure 5(b) represent latitude and longitude respectively. This displays one loop around the test path on the latitude and latitude axis. The data was reconstructed and time-matched to display the vehicle's travel with all five GPS records, with the current position being the actual position of the vehicle at a given time. From this test, an additional 680 meters of NLOS path history is displayed outside of the communication range of the RSU.

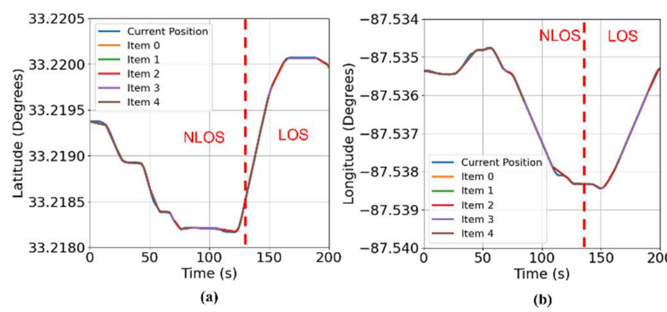

Fig. 5. Reconstructed path history over true position; (a) Latitude, (b) Longitude

Items 0 through 4 represent the path history at a specific location with a particular offset. Item 0 contains the most recent path history; the higher the item number, the older the corresponding path history is. Item 0 represents a location that the vehicle traveled through 5 seconds ago, while item 3 represents a position the vehicle was in 15 seconds ago. The result shows an excellent match of the path the vehicle took when compared to the original data. As the vehicle travels south, the latitude begins to decline, remaining stationary as the vehicle travels westbound. When the vehicle turns right and travels north, the latitude begins to climb between 125 and 160 seconds. The vehicle then travels east back to the starting location, turning south into the parking lot at 200 seconds. In this real-world test, path history is shown to record data up to 600 meters in delay, the hand-off process demonstrates how a new point is generated every 2.5 seconds. Utilizing this data element, a single RSU placed centrally could act as the ITS system for traffic lights in a 1 km radius around the system.

III. Potential Use Cases of Path History

Utilizing the previous testing, a potential use case model can be created. An example of this model is shown in Figure 6. This model presents two independent traffic controllers A and B linked together with a centralized server, with a network. Traffic controller A is a standard traffic controller available to change light timings and report these values on the network. Traffic controller B is the same traffic controller but equipped with ITS-capable equipment such as a C-V2X RSU. The two intersections were spaced sufficiently far apart, where a C-V2X-equipped vehicle in intersection A cannot communicate with intersection B. Vehicle path history is recorded by traffic controller B's RSU. The data is forwarded to a centralized traffic server that can process and submit light timing requests to a networked traffic controller.

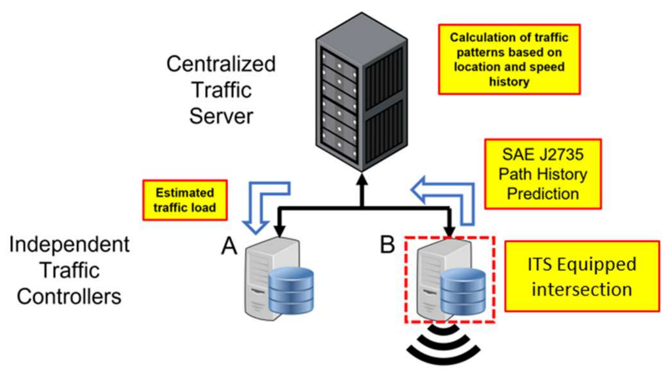

Fig. 6. Traffic network featuring a centralized server with 2 traffic controllers, one was equipped with ITS

A. *Scenario 1: Traffic Jam*

Using this model, two scenarios can be applied to this network model. In scenario 1, multiple vehicles enter controller B's communication range over an intermediate span of time. The path history is received and sent to the centralized server. The server determines that the vehicles traveled through Intersection A based on the path history from forwarded by Intersection B. The server notices a trend where vehicle speed dramatically slows down in Intersection A, based on the time offset and distance offset provided by the PathHistory element. This trend occurs over a prolonged period, leading the server to identify unusually high traffic congestion at Intersection A. Since this intersection lacks visibility to this information, the centralized server sends prioritized requests to the traffic controller. These requests were held until traffic starts to ease at Intersection A, as detected by the sensors at Intersection B.

B. *Scenario 2: Vehicle Crash*

In this scenario, we utilize Intersection B's RSU. Vehicles have entered Intersection B from the same direction. Over time the path history reveals that vehicles were consistently changing lanes and traffic slows down around them. With this information, the centralized traffic server can determine that a potential accident may have occurred. This could trigger a rescue alert without the need for pedestrian calls.

IV. Conclusion

A real-world test was created to establish and present the use cases of the path history element. The data showed the ability to read path history up to 1 km into the past of vehicle travel. Path history data could benefit C-V2X systems for the reduction of traffic jam, prediction of potential crashes, and lane abnormality.

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