V2X-Locate Positioning System
Whitepaper

November 8, 2017

1 Introduction

The most important piece of information any autonomous system must know is its position in the world. This is especially true for vehicles, where the entire purpose is to get from where you are now to your destination. The more accurately a vehicle knows its position, the more it will be able to understand itself and its surroundings. Accurate vehicle positioning is vital for safe and reliable operation of Connected Autonomous Vehicles (CAV) and Vehicle-to-X (V2X) applications in all operational scenarios. These requirements are quantified in several standards globally. For example SAE specifies a 1.5m requirement must be met 68% of the time [1]. However, in many important use cases Global Navigation Satellite Systems (GNSS), even assisted by dead-reckoning sensors and atmospheric corrections, fail to provide a reliable position. Typically GNSS positioning performance degrades in areas such as

- Urban canyons
- Tunnels
- Parking garages
- Any other compromised sky view.

Dead reckoning relies on inertial sensors which drift with time and cannot be used for absolute positioning. Exemplifying this statement, a state-of-the art automotive grade dead reckoned GNSS positioning system, driven in a straight line, within the urban canyon environment of New York City is shown in Figure 1. Such failures result in unpredictability and indeterminism of vehicle position, leading to potentially erroneous decision making and unsafe manoeuvres, effectively compromising the safe operation of CAVs.

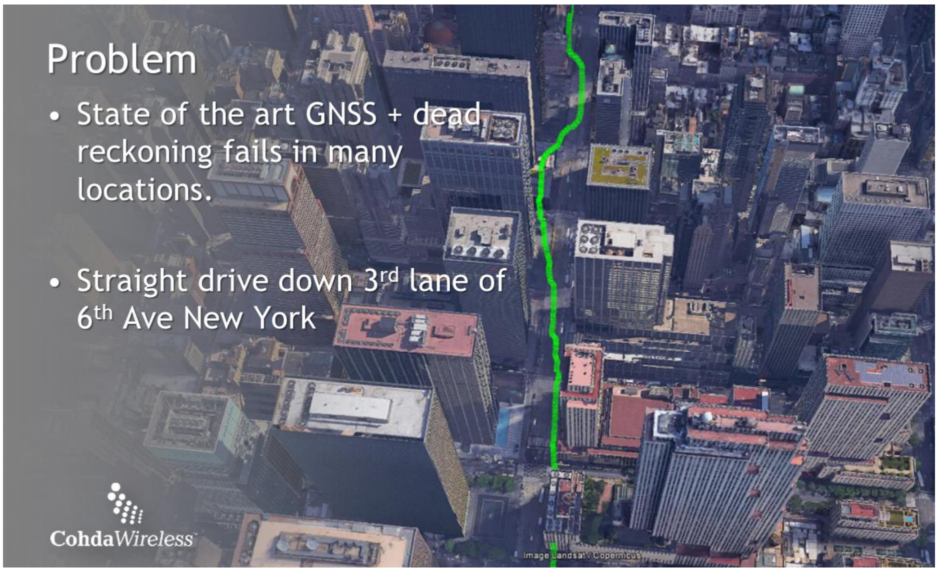

Figure 1: PROBLEM WITH STATE OF THE ART DEAD RECKONING GNSS

2 V2X-Locate: How does it work?

In V2X, vehicles communicate with other devices (vehicles, infrastructure, pedestrians, etc.) using wireless communication systems such as Dedicated Short Range Communication (DSRC) or IEEE 1609 or ETSI ITS. Both standards use IEEE 802.11p as the underlying physical and medium access layer technology. In V2X deployments, vehicles are equipped with On-Board Units (OBU), while infrastructure is supported by installation of Road Side Units (RSU).

RSUs are typically deployed by road authorities or third parties (like parking garage operators, petrol stations etc.) at fixed locations, primarily to provide back-haul and/or locally managed services. In addition, these RSUs generally broadcast their position information in either,

- Wave Service Announcements (WSA) (IEEE 1609)
- Geonetworking messages (ETSI ITS)

Thus, the location of these RSUs is well known to any vehicle which is within communication range. V2X-Locate uses ranging measurements to these fixed RSUs to enable enhanced positioning accuracy as demonstrated in Figure 2.

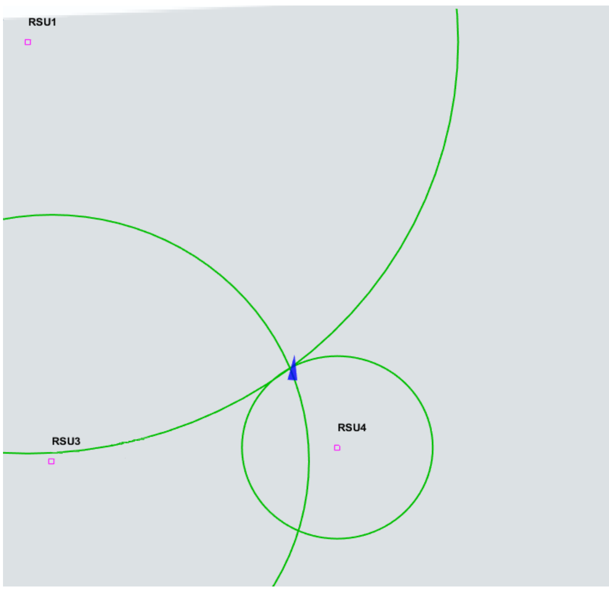

Figure 2: V2X-LOCATE RANGING

The vehicle is shown as a blue triangle and the ranges to RSUs are illustrated as intersecting green circles. Each circle is centred on an individual RSU's known location with radius equal to the range measurement. These ranges from spatially separated RSUs are fed into Cohda's enhanced positioning engine to accurately position the vehicle. This positioning engine provides information at the facilities layer of the software stack of the OBU.

3 What enhancements does it provide?

A key problem with any ranging based solution is the error distribution of the range measurements. A signal transmitted over the wireless channel suffers from multipath effects. This can result in performance degradation of any ranging based system. For example, multipath is the main cause of degradation of GNSS in urban canyons due to reflections off buildings and other structures, which extends and/or interferes with the true line-of-sight signal. Note these cannot be corrected using atmospheric corrections shared in systems such as WaaS. Cohda Wireless has developed and implemented enhanced signal processing algorithms, to improve robustness with regard to multipath effects. A combination of accurate timing and multipath aware enhancements are used to achieve range accuracy in the order of nanoseconds Time-of-flight, in even severe multipath channels (often the case in underground car parks, tunnels, mines, urban canyons etc.).

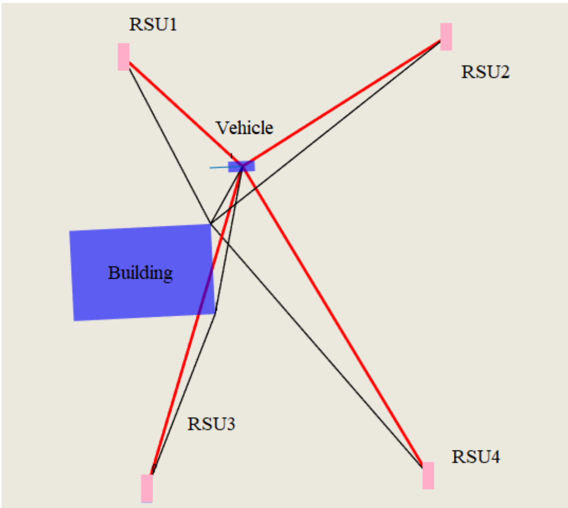

Figure 3: COHDA WIRELESS SIGNAL PROCESSING IP SOLVES THE PROBLEM OF RANGE EXTENSION

In Figure 3, we show the impact of multipath reflections from a building. Non-multipath aware devices may measure ranges well over the true value due to these reflections, causing inaccurate position estimates. In this case the receiver frontend may not correctly place the packet timing on the true line-of-sight path. Through advanced processing capabilities of Cohda's Software Defined Radio (SDR), the V2X-Locate solution is able to correctly identify the correct packet receive time based on the true line-of-sight path, regardless of the existence of multipath signals (as shown by red LOS lines).

The approach assumes that RSUs honour the IEEE 802.11 requirements around Short Interframe Spacing (SIFS) timing. This requirement specifies how IEEE 802.11 devices should respond to Unicast packets with a short Acknowledgement at a very specific period of time after receipt of the Unicast packet. Many 802.11 chipset implementations tested do indeed support such requirements. However, for the best performance in all scenarios, it is recommended to utilise Cohda's RSU and OBU hardware.

4 How does it compare to GNSS?

The performance of V2X-Locate compared against a state-of-the-art automotive grade GNSS module in an ideal open sky condition is shown in Figure 4. For this comparison, the two solutions were installed in a vehicle that was driven in a rectangular path along predefined reference lines in an open car park. The DSRC and GNSS antennas were co-located within the vehicle's sharkfin antenna (less than 2cm spacing between them). The Cumulative Density Function (CDF) shows the lateral error, as compared to the predefined reference lines, of both the GNSS and V2X-Locate solutions over 5 repetitions of the trial.

In perfect GNSS conditions V2X-Locate can match and even surpass GNSS performance. After all, there is no need to track satellites that are 12,000 Miles away travelling at 9,000 Miles/Hr, rather the RSUs are a few hundred metres away, stationary and at fixed locations.

In Figure 4 we show GNSS (with Dead reckoning and WAAS) and V2X Locate operating effectively in idealised "Open Sky View" conditions such specified in SAE J2945/1 [1]. Both meet the SAE performance requirements. V2X Locate was better than 91cm 95% of the time, whereas GNSS was better than 2.5m 95% of the time.

The utility of V2X-Locate is particularly evident in GNSS challenged locations. Urban areas experience the majority of traffic congestion, and are also prone to poor GNSS performance due to "Urban Canyons" caused by large buildings. Indeed these locations are precisely where V2X RSUs will be deployed by cities and road authorities.

New York, USA is one location that experiences both of these problems. To demonstrate the utility of the V2X-Locate solution in such environments, V2X RSU infrastructure was installed along a test section of 6^{th} Avenue, New York and a vehicle equipped with both V2X-Locate and GNSS solutions driven in a straight line down the third lane. As expected, GNSS performance is significantly challenged within this exemplary environment as shown in Figure 5. In contrast, Cohda's V2X-Locate positioning system is able to achieve sub-metre accuracy.

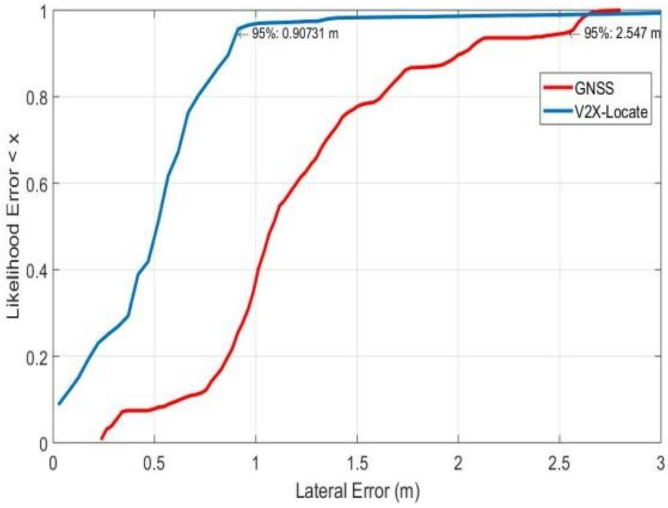

Figure 4: COMPARISON OF V2X-LOCATE WITH GNSS IN IDEAL OPEN SKY CONDITIONS

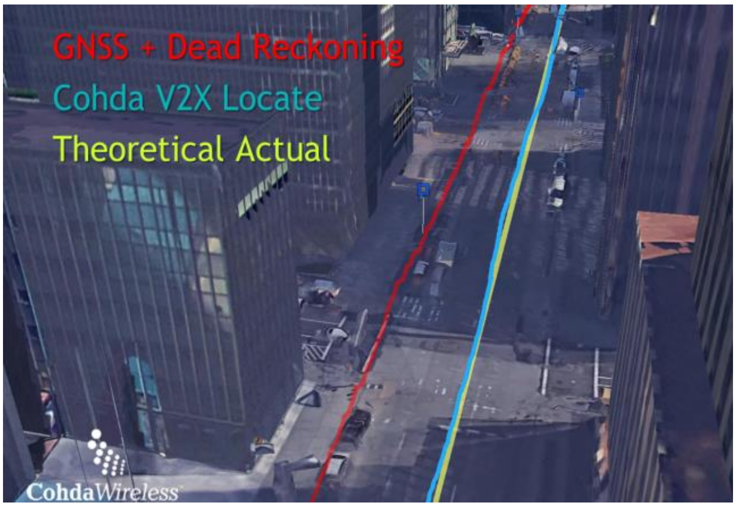

Figure 5: V2X-LOCATE VS. DR-GNSS IN NEW YORK 6^{TH} AVE.

5 V2X-Locate Integration

Cohda's V2X-Locate solution integrates vehicle sensors such as speed, yaw rate and Inertial Measurement Unit (IMU) output to improve the robustness and accuracy of the positioning solution. Additionally, the V2X-Locate solution can seamlessly integrate GNSS data if it considers the data to be of sufficient quality. The overall solution architecture that integrates RSU ranging measurements, vehicle sensors and GNSS data is shown in Figure 6.

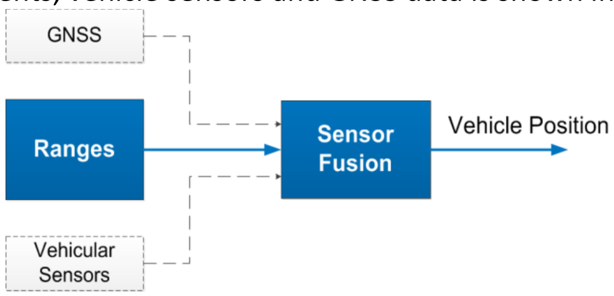

Figure 6: COHDA WIRELESS V2X-LOCATE SOLUTION

5.1 Benefits

By utilizing DSRC signals and Cohda's enhanced signal processing and positioning algorithms, Cohda has developed a product to provide accurate vehicle position irrespective of GNSS availability and/or quality. Additionally, V2X deployments benefit from this solution as no extra hardware (in addition to V2X equipment already installed) is required. This simplifies deployments and system integration efforts as well as providing hardware related cost savings

5.2 Operational Scenarios

The V2X-Locate solution is not intended to replace GNSS solutions, but instead compliments and integrates this technology. Thereby creating a solution that not only operates in ideal GNSS environments, but also GNSS challenged environments to enable an integrated platform capable of operating in all V2X and CAV operational scenarios.

Such environments that benefit from use of the V2X-Locate solution include,

- Mining (underground tunnels)
- Bus, tram and train yards
- Multi-storey car parks
- Underground car parks
- Urban canyons

[1] SAE J2945/1 201603 - Dedicated Short Range Communication (DSRC) "Minimum Performance Requirements", March, 2016