LANE-LEVEL VEHICLE POSITIONING USING DSRC AS AN AIDING SIGNAL

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SUMMARY

Many new advanced driver assistance and ITS applications will require vehicle-based lane-level position determination. Although Global Navigation Satellite Systems (GNSS) can estimate vehicle position to a few meters, it is necessary to integrate a variety of navigation technology to be able to get sub-meter accuracy required for lane-level positioning. Further, we want to accomplish this with low on-vehicle and infrastructure cost, and be able to accomplish in any location (availability) at all times (continuity).

One of the promising solutions is to perform data fusion from a variety of sources, including GNSS (e.g., GPS) receivers, inertial measurement devices, wheel based encoders, and Ground Based Radio Systems (GBRS). There are a number of ground based radio systems, but using a network of DSRC receivers is appealing since they are already being deployed for other ITS applications. The proposed architecture would utilize roadside DSRC units in including timing information in its broadcasts so that an on-board vehicle receiver can improve its vehicle position estimate. These public sector infrastructure solutions could significantly improve nationwide positioning capability. This vehicle-infrastructure DSRC architecture offers the capability to supplement other positioning methods for roadways where other methods are not available at comparatively low cost or are not sufficiently accurate or reliable. This enhanced capability would enable applications that require lane level positioning such as intersection collision avoidance, road departure warning, and automated vehicle lateral or longitudinal control.

We propose a DSRC-based positioning architecture to enhance lane-level positioning accuracy in diverse driving environments, satisfying our positioning needs of accuracy, availability, continuity, and low-cost. This DSRC positioning architecture improves vehicle positioning viability and benefits, while reducing limitations and obstacles for different approaches based on technological, business, and deployment characteristics. For example, it is envisioned that local vehicle-to-vehicle and vehicle-to-infrastructure communications systems will be put in place for a variety of driving applications (e.g., intersection collision avoidance, road departure warning, advanced travel information, etc.). These DSRC communication systems can be used for positioning by various methods, described in the technical approach. This would be a tremendous side benefit. Currently, the communication systems are being defined and installed primarily for exchanging information to support Connected Vehicle applications. Now is the time to determine if any improvements to messaging protocol and timing signals are required to also use DSRC communication signals to aid in vehicle positioning.

This proposed DSRC architecture will enable and expedite the development of accurate, reliable vehicle positioning systems. It is anticipated that the experience, deliverables, and outcomes achieved from this communications architecture will contribute to the maturity of the Connected Vehicle network in the U.S. The DSRC positioning architecture and technical description describes the following evaluation metrics 1) positioning accuracy, 2) ability of the positioning system to operate reliably in all driving environments (reliability, availability, continuity), and 3) achieving low-cost deployment.
VISION

By developing an accurate, reliable, and low-cost vehicle positioning system that can be readily deployed, a number of intelligent transportation system applications become possible. These positioning systems will have significant impact on **roadway safety**, through applications such as lane-departure warning, freeway merge assistance, intersection collision avoidance, reverse assistance/warning, and curve over-speed warning [US DOT 2008]. Further, these new generation positioning systems will also have a positive impact on **mobility**, by enabling applications such as vehicle navigation assistance, congestion warning systems, adaptive cruise control, and parking assistance. Lastly, new generation positioning system development will also enhance **energy/environmental** issues (e.g., reduction in vehicle emissions and lower energy consumption), primarily through the mobility improvements cited above. With regard to the contribution and relevance to related FHWA highway programs and activities, this DSRC-enhanced positioning system is directly relevant to the Connected Vehicle program being pursued by the US Department of Transportation. The aim of the Connected Vehicle program is to deploy an enabling communications infrastructure that supports vehicle-to-infrastructure, as well as vehicle-to-vehicle communications, for a variety of vehicle safety applications and transportation operations. In addition, this research will directly benefit the advancement of autonomous ground vehicles facilitating a number of different applications, such as GIS-based urban data collection for mapping applications, and monitoring urban infrastructure for situational awareness [Barthels 2006].

TECHNICAL RATIONALE

No single independent sensor technology is capable of simultaneously attaining the accuracy and availability specifications required for lane-level positioning in the expected diversity of vehicle environments. Global navigation satellite systems such as GPS can provide good performance in open areas where satellite signal can be received, however they have degraded performance in dense urban areas where the satellite signals are blocked by buildings and obstacles. Inertial Navigation Systems (INS) can provide positioning solutions in all environments; however their accuracy drifts over time without updates. Feature-based navigation using computer vision, laser ranging, or radar can be successful only if there are sufficient features that can be extracted from the driving environment. Ground Based Radio communication systems, such as DSRC, can offer useful information for reliable determination of vehicle position and have the added advantage that their performance characteristics can still be influenced by the engineering community interested in roadway applications.

It is clear that in order to meet the positioning requirements of accuracy, reliability, and continuity, a variety of these sensors will need to be combined. When implementing such on-vehicle data fusion applications, the following technical issues are critical:
- **Asynchrony**: The measurement time-of-applicability for different sensors will be distinct. Fusion of the sensor information requires a means to propagate the navigation information to the time-of-applicability of the different sensors.

- **Latency**: Processing within each sensor and communication of the sensor information from each sensor to the data fusion CPU result in latency between the time-of-availability of the sensor data and its time-of-applicability. Failure to correctly compensate for this latency results in position errors that are the product of the vehicle speed and the latency, which can easily exceed the position error specification.

- **Reliability**: Different combinations of sensors will be available under different environmental conditions, yet the navigation system must reliably provide a vehicle position estimate at a known rate (typically high). In addition, it would be useful to the systems using the position data to have quantifications of both the estimated position accuracy and its rate of growth.

Integrated (or aided) navigation systems, as depicted in Figure 1, provide the means to address each of the above critical issues. Integrated navigation is a time-tested approach to the fusion of asynchronous, possibly latent, data from a diversity of sensors to reliably estimate vehicle state information on aircraft, submarines, and land vehicles [Farrell 2008, Farrell & Barth 1999]. For automotive navigation systems, the high-rate sensing typically includes integration of either inertial measurements or wheel encoder readings. The readings from these sensors, especially inertial measurements, are essentially unaffected by environmental conditions and reliably available at high rates. Integration of the data from these high-rate sensors, through the kinematic equations of the vehicle, provides a reliably available estimate of the vehicle trajectory at a high rate. The accuracy of this vehicle state estimate will vary with time depending on the availability of the aiding sensors. Importantly, the sensor fusion algorithm maintains an estimate of the state accuracy and its rate of growth. The system designer will attempt to ensure that the suite of aiding sensors will always achieve the accuracy specification; nevertheless, this onboard monitoring of the accuracy is a desirable real-time check of that specification. The fact that the recent past history of the state (i.e., vehicle trajectory) is available allows the sensor fusion algorithm to properly accommodate asynchronous and latent sensor measurements.

![Figure 1. Integrated (or aided) navigation system architecture.](image-url)
In this integration approach, the high-rate sensor (e.g., inertial measurement sensors) is the basis for estimating the vehicle state (position, velocity, attitude) continuously, with a number of other sensors (e.g. DSRC) enhancing the state solution accuracy. Due to their high cost of installation and maintenance, this architecture does not consider dedicated infrastructure methods such as embedding of magnets or RF signal generators in the roadway.

The GNSS and GBRS sensors directly provide range measurements, which can be combined to estimate position, when a sufficient number of measurements are available. Feature based methods may provide range, azimuth, elevation measurements which either alone or via combination with other sensors may again provide estimates of vehicle position. To combine any of these sensor measurements, latency and time-synchronization issues must be addressed. Without the reference trajectory obtained by integrating the high rate sensor, such data fusion can be quite challenging. In the integrated navigation approach the purpose of the aiding sensors in the sensor fusion system is to estimate the error in the vehicle state and to calibrate the parameters of the high rate sensor system. For a given combination of aiding sensors, the aided navigation system depicted above will always perform better than the given combination of aiding sensors without the high-rate system.

**VEHICLE POSITIONING BACKGROUND**

In this proposed architecture, we plan to describe and DSRC enhanced vehicle positioning systems from an integrated navigation approach, as depicted in Figure 1. This section presents a short review of the various technologies and their comparative features.

**High-Rate Approaches (Kinematic Integration)**

The main idea of kinematic integration is that high-rate sensor readings are integrated through a kinematic vehicle model to produce a continuously available estimate of the vehicle state trajectory. Here, “continuously available” means that the availability of the vehicle state estimate is not dependent on the availability of any external (electro-magnetic) signals. This is in contrast to the aiding signals, which are each in some way derived from electro-magnetic signals, which may be temporarily unavailable. For roadway applications the dominant kinematic approaches are inertial navigation [Ch. 11 in Farrell 2008] and encoder-based dead-reckoning [Ch. 9 in Farrell 2008].

Inertial navigation uses angular rate and acceleration measurements from an inertial measurement unit (IMU). Integration of the angular rates yields a transformation for vectors from sensor frame to navigation frame which is used to rotate the measured acceleration vector from the sensor frame to the navigation frame. Subsequently, its integration yields the desired navigation frame position and velocity vectors.

Encoder based dead-reckoning uses digital measurements of the angle of rotation of each wheel to determine the vehicle forward speed and turn rate. In many modern vehicles, the angle-of-rotation of each wheel is freely
available on the vehicle CAN bus, as this information is used onboard for safety augmentation systems such as anti-lock braking systems (ABS). Integration of turn rate provides an estimate of vehicle yaw angle which can be used to transform the vehicle forward speed to the navigation frame where it can be integrated to yield the desired estimate of the navigation frame position.

Due to the integrative nature of these processes, the high-frequency portion of the measurement noise is greatly attenuated, while the low frequency portion of the measurement noise is amplified. In fact, over sufficiently long periods, the integrated error can become unsatisfactorily large unless corrected by some form of aiding signal, such as DSRC. The integrated error grows slowly and its rate of growth can be accurately predicted at the design phase and in real-time. Therefore, while the design of the aiding signal system is intended to ensure that the position specification is continuously achieved (i.e., the availability specification), if some aiding signal fails, then the system is able to predict the error growth and notify the user whether to stop using the system.

The encoder-based approach uses information already available on the vehicle; however, wheel slip will induce yaw and position error. Such wheel slip is not predictable at the design stage and does depend on environmental conditions. IMU-based approaches involve additional sensors, and thereby incur higher cost, but their error characteristics are completely known at the design phase and are unaffected by the vehicle trajectory and environmental conditions. Even a low cost IMU can attain centimeter-level accuracy and maintain lane-level accuracy for tens of seconds after aiding signals become unavailable. This coasting time is more than sufficient to alert the user. While GPS-aided INS approaches are now common place, the first demonstration of a differential carrier phase GPS-aided low cost IMU that is known to the authors is described in [Farrell et al 2000]. A key attribute of such systems is that during the time periods when aiding sensors are available, the information from the aiding sensors is used to calibrate the sensors used in the kinematic approach. This calibration increases the performance of the kinematic approach at future times. Additional examples of high accuracy aided navigation systems for highway vehicles are described in [Farrell 2003, Yang et al 2003a, Yang et al 2003b].

Kinematic integration based methods provide position, velocity, and reference frame transformations. These quantities are necessary for use of all the aiding systems described below.

**Aiding Sensors—Global Navigation Satellite Systems**

Global Navigation Satellite System solutions are one of the most convenient and accurate methods for determining a vehicle’s position within a global coordinate system [Farrell & Barth 1999]. As such, utilization of a GNSS receiver has become the most prominent method of determining the physical location of a vehicle for many navigation applications. These systems are based on a constellation of satellites that orbit the Earth, where the orbits are designed in a manner that allows the signals from at least four satellites to be received simultaneously at any point on the surface of the Earth. A GNSS receiver on the surface of the Earth utilizes the
signals from at least four satellites to determine its own antenna position \((x, y, z)\) according to various measurements of the pseudoranges between the satellites and the receiver antenna. The receiver measurements include various code-based pseudoranges and potentially carrier phase information. The standard deviation of uncorrected GNSS position estimates is on the order of 10 meters. Improved accuracy can be obtained by using differential techniques to remove the common-mode error from the measurements, making the standard deviation of the error small enough to satisfy lane-level accuracy requirements. Even further accuracy is possible using additional corrections such as carrier phase corrections and/or dual channel measurements.

Although several GNSS constellations exist (e.g., GPS, GLONASS, Galileo, Compass), GPS is currently the most advanced. The GPS modernization program promises to greatly enhance the utility of the GPS system for highway applications. Availability of three civilian frequencies will allow users to compensate for ionospheric effects which are the dominant error source. It will also enhance positioning integrity for safety-of-life applications. Removal of encryption on the L2 signal will allow multifrequency receivers at considerably lower cost. Also, carrier phase integer ambiguity methods will be facilitated by the longer wavelengths possible. In addition to the enhancements to the GPS constellation, GPS receivers are steadily advancing. High sensitivity receivers originally designed for indoor applications are able to track signals even in some challenging urban environments; however, those environments are still multipath challenged.

To obtain accurate 3-D positioning solutions using GNSS, it is necessary to directly receive signals from four or more satellites. If these signals are blocked by buildings, tunnels, or obstacles, then an accurate solution cannot be obtained. There are a variety of potential solutions to overcome this fundamental problem, including the use of pseudolites, integration with inertial navigation systems, and feature-based techniques. These approaches are briefly described below.

**Aiding Sensors—Feature-Based Solutions**

In recent years, there have been several research efforts to use egocentric sensor information to assist with vehicle positioning. Typical egocentric sensors may include digital cameras, LIDAR range sensors, or RADAR systems. These sensors are attractive, since they naturally complement other aiding sensors, such as GNSS receivers. GNSS position solutions are most accurate and reliable when there are few obstructions (i.e., structures) to the user-to-satellite line-of-sight. On the other hand, egocentric sensors rely on availability of local reflective structural features that can be observed (i.e., points, corners, lines, surfaces, etc). These features can be extracted from the sensor data and then used for position and heading determination. Therefore, when GNSS signals are blocked by structures, the features observed by egocentric sensors can play a large role in positioning. When there is a lack of local structures, the GNSS solution is expected to be sufficiently accurate.

Feature-based positioning systems using digital cameras have become increasingly attractive since the costs are low and many state-of-the-art driver assistance systems are already using cameras for various tasks. In recent
years, much research has been carried out with on-board camera imagery using Simultaneous Localization and Mapping (SLAM) techniques (see, e.g., [Davison 2007]; [Newman et al., 2006; Bento et al., 2005; and Guivant et al., 2007]). These SLAM techniques typically consist of two processes: 1) the extraction of multiple features from the camera imagery, which can be tracked from frame-to-frame and 2) estimating relative vehicle position and orientation using an Extended Kalman Filter (EKF). This EKF typically utilizes short-term changes of vehicle state, usually provided from odometry, an IMU, or GPS. Computer vision techniques are applied to the video image stream, extracting features such as unique textures or lines in the environment. In man-made urban environments, lines are a very common feature, corresponding to buildings, roadway infrastructure, etc. Information from a kinematic integration system can greatly facilitate tracking of features between frames and solution of the feature correspondence problem. Tracked features can either be used to compute relative vehicle position or for correction (i.e., aiding) of the kinematic solution. Single camera systems have limited observability as depth and scale are not separately observable for objects of unknown size. More robust techniques use stereo imagery from two (or more) cameras [Schleicher et al 2007]. Other methods exist that use omni-directional vision sensors and multi-baseline stereo algorithms [Ishiguro et al. 2001]. Omni-directional vision sensors are well suited for the localization algorithms since they can measure precise azimuth changes of features over many image frames.

In terms of absolute positioning, known image landmarks (previously surveyed) can be detected and utilized, as is done in the European Project SAFESPOT [Brignolo et al. 2009], whose goal is to achieve lane level positioning using image landmarks detected in on-board camera imagery. Such an approach works well with the VII infrastructure and will be discussed more below.

In addition to computer vision, other research is underway to use other sensors such as laser scanners (i.e., LIDAR) or radar to aid the position estimation [Soloviev 2008]. Similar to computer vision, a 2D laser scanner can detect features such as building walls, measuring distances to reflecting surrounding objects within a specific angular range. The features typically extracted from the range images are lines, again because they are a very common feature in man-made urban environments. In a range image, building walls are lines, and corners of buildings are intersections of lines. These features are robust from frame to frame and can be tracked as a reliable distance measurement. Changes to these line features between frames are used to estimate position and orientation changes to the vehicle. Range imagery is robust for positioning as long as there is sufficient structure within range of the sensor. Similar to digital cameras, ranging sensors are becoming more commonplace in vehicles for other on-board safety systems, such as automatic cruise control.

It is important to point out that vision, LIDAR, and radar methods have some serious issues that must be considered within roadway applications. Most vision systems are passive, relying on ambient light. Alternatively, LIDAR and radar are active, broadcasting electromagnetic energy and measuring the time delay until the reflected signal is received. LIDAR and radar approaches would require some form of orthogonal
coding to function reliably in a multi-vehicle system. In roadway applications, for any of the three approaches discussed in this paragraph, it would be possible and inexpensive to augment the highway infrastructure with local emitters or reflectors along the roadway at known locations. The local VII infrastructure could broadcast the locations of local features, emitters, and reflectors, thereby greatly simplifying the on-vehicle computational requirements.

**Ground Based Radio Systems—Connected Vehicle DSRC Aiding Sensors**

Various forms of position aiding signals may be derivable from ground based radio systems, such as radio broadcasts, TV broadcasts, pseudolites, cell phones, or Connected Vehicle DSRC modems. These architectures are still not mature, but offer potential low cost approaches to greatly improving the ability to estimate reliably the position of vehicles to lane-level accuracies.

Dedicated Short Range Communications (DSRC) draws upon the increasingly popular IEEE 802.11 Wi-Fi standard. Within the IEEE 802 context, Wireless Access in Vehicular Environments (WAVE) utilizes the DSRC technology for V2V communication and V2R communications. The 802.11 efforts in WAVE applications are being developed into the 802.11p standard. Equivalent efforts are occurring with the IEEE 1609 working group and standard for Dedicated Short Range Communications. The 802.11p and 1609 standards are for data-only systems and operate on radio frequencies in the 5,725 MHz to 5,875 MHz Industrial, Scientific and Medical (ISM) band. The set of standards developed to support this interface provide a short to medium range communications service for a variety of applications, including public safety (obstacle detection, collision warnings and avoidance, intersection safety), commercial vehicle applications (weigh-in-motion/inspection clearances, border crossing), electronic toll collection, parking lot payment, in-vehicle signing, and many others.

DSRC technology provides secure, reliable communication links between vehicles and infrastructure safety subsystems that can increase highway safety. The 5.9 GHz DSRC link uses RF broadcast techniques to transfer data over short distances between roadside and mobile units, between mobile units themselves and between portable and mobile units. This link enables operations related to the improvement of traffic flow, highway safety, and other ITS applications in a variety of application environments called DSRC/WAVE. 5.9 GHz DSRC system requires robust, fast, localized transmissions from vehicle-to-vehicle and vehicle-to-infrastructure to serve the many public safety and private commercial applications. However, for high-speed vehicular applications, significant changes were required to provide latency minimization, channel switching/prioritization, authorization, prioritization and anonymity without compromising messaging integrity, correctness, privacy, & robustness attributes.

The National ITS Architecture has identified DSRC as a primary means of communicating between the vehicle-to-infrastructure, and from vehicle-to-vehicle. There are a large number of applications planned within the ITS
domain, including collision avoidance, traffic management, toll collection, transit operations, commercial vehicle operations, and traveler information. In addition to these ITS applications, WAVE and DSRC are expected to support another set of applications that would be of broader interest to motorists and those interested in providing services to these motorists. Some of these applications would be using the DSRC device as a means of connecting the vehicle to the Internet.

The Connected Vehicle infrastructure has the unique advantage that its design is defined by the surface transportation community. There are several options to use the Connected Vehicle communication infrastructure to possibly aid in a vehicle position determination. A few ideas are outlined below.

Measuring the time-of-flight of the roadside DSRC transmitter signals by the receiver will allow accurate measurement of range to the DSRC modem. This time-of-flight measurement is only possible if there is appropriate timing information in the signal itself. When the location of the DSRC modem antenna is accurately known and the DSRC signal has timing information as part of its message, the absolute range of the vehicle to the transmitter can be achieved. This range information can be used to reduce the positioning errors along the line of sight to the transmitter, aiding in the overall positioning solution. For example, if the DSRC transmitter is mounting on a traffic light (as shown in Figure 2), then the range between the antenna and the receiver (vehicle) can improve the position estimate along the line of sight to the antenna. The overall concept is illustrated in Figure 3.

![Figure 2. DSRC antenna being mounted on or near a traffic signal.](image)
Position error when using DSRC ranging

Position error without using DSRC ranging

Figure 3. The positioning error shown in red is improved along the direction of the line-of-sight to the DSRC antenna, resulting in the positioning error in blue.

In addition to the above ideas, if the vehicle includes egocentric sensors for use in feature based methods, a large portion of the related computations is required for feature selection, feature tracking, and feature correspondence. The Connected Vehicle DSRC could broadcast messages containing the characteristics and location of known features in the local area. This information would greatly reduce the complexity of the per vehicle computations; thereby reducing the cost of the on-vehicle instrumentation. This DSRC V-I architecture provides a more robust determination of vehicle position.
DSRC POSITIONING TECHNOLOGY PRINCIPLE

DSRC has been considered as a promising on-vehicle communication method in recent years. It works on 5.9 GHz frequency in the U.S. authorized by the FCC and on 5.8 GHz in Europe and Japan. DSRC provides low-latency and high-speed communication service which is most widely used in ETC (Electronic Toll Collection), public safety related services, traffic management, etc. The coverage is typically up to 100m (for high rate communication) and 300m (for low rate emergency warning).

DSRC follows the IEEE 802.11p standard, which is similar to existing wireless LANs – 802.11 a/b/g. Like OSI 7-layers, DSRC has a 3-layer architecture – L1 (Physical layer), L2 (MAC and LLC), and L7(Application). Orthogonal Frequency Division Multiplex (OFDM) is the basic modulation method. OFDM is a spread spectrum modulation method in high rate communication systems in which another prevalent method is CDMA. In DSRC, symbol rate remains constant but data rates vary with coding rates.

Most applications on DSRC are focused on communication issues, with very few pursuing positioning using DSRC signals. However, because of the similarity of DSRC with 802.11 wireless networks, positioning methods in 802.11 have been surveyed as potential radio-navigation positioning methods.

The MAC layer and physical layer are very similar to 802.11a on 5.0GHz, with some parameter differences. Signal sequence in physical layer is composed of PLCP Preamble (short training sequence and long training sequence), signal field and data. The training symbols are predefined sequences used for the purpose of synchronization and channel estimation. Training symbols can also be taken as the location service signals used in determining TOA or TDOA, as shown in Figure 4.

![Figure 4. Physical layer signal sequence.](image)

The physical signal transmitted is modulated with OFDM (Orthogonal Frequency Division Multiplex), which is a popular spread spectrum modulation method that can be seen in digital TV, DSRC and 802.11a. Channels are divided into orthogonal sub-channels, where data is divided into groups and transmitted in parallel. Complex OFDM symbols in frequency domain are converted into time domain using IFFT, before they are transmitted. The received time domain signals are converted back into complex symbols with FFT. The time between the end of IFFT process and the beginning of FFT process is the TOA or propagation time which is in direct proportion to the range between transmitting and receiving antennas.
**Existing Implementations**

Although ranging using received signal strength is easy to carry out in 802.11/DSRC networks, the signal strength model with range is inaccurate so that the range accuracy estimated with signal strength is unacceptable for lane level positioning, and thus is not discussed here. Methods of positioning based on signal timing and range measurement can provide lane-level accuracies as long as timing information is provided in the DSRC signal. The accuracy of propagation time measurements directly influences the range accuracy. Several methods have been proposed for time measurements in OFDM based 802.11 networks as described below:

One proposed general timing method described in [Chih-Yu Wen et al. 2007] utilizes ad hoc sensor networks based on either asynchronous clocks or phase shift. The distance estimation via asynchronous clocks makes up a scheme so that the clock error due to asynchronous clock is measured first and then round trip time is measured. The distance estimation via asynchronous phase shift uses similar measuring mechanism to the carrier-phase GPS, and integer ambiguity also needs to be solved.

An alternate RTT (Round Trip Time) method is measured with MAC frames, as described in [Ciurana et al. 2007]. The MAC signal is used to trigger an external timer to count the travelling time in the experiments. Due to channel randomness, the estimates may vary, so that multiple estimates are required to reach an accurate estimate.

An additional approach [Feng He et al. 2007] studied the timing and ranging based on frame synchronization. Frame synchronization is the clock and frequency synchronization on the baseband before data in signals is processed.

A final study [Hämäläinen et al. 2009] proposed a method for OFDM wireless networks, based on calculation of the phase shift of subcarriers. The method is actually based on round trip measurements, while the time is measured with phase shift.

Real world experiments and simulation implementations have demonstrated positional accuracies for Wi-Fi implementations. Simulation results [Hämäläinen, A. et al, 2009] shows a distance estimation error mean of 2.17m and deviation of 4.16m. Experiments of the RTT method gave an estimation error of less than 1.5 meters [in Ciurana, M. et al, 2007].

**CONCLUSIONS**

There has been very little experimentation using DSRC for positioning, therefore the performance is difficult to quantify at this time. The positioning accuracy depends largely on geometric conditions, and the number of well-placed transmitters. System architecture, experiments, and simulation data suggest that lane-level positional
Aiding is feasible with DSRC, as long as timing information is provided as part of the signal. Drawbacks exist such that extensive roadside infrastructure along the roadside would be required to provide continuous coverage. Therefore, DSRC is an ideal vehicle aiding technology for challenged vehicle environments.

As described above, there are several architectures that could be used to improve on a GNSS or GNSS/inertial positioning solution. Promising opportunities exist that would use DSRC radio modems for positioning. In particular, if advanced driver assistance system applications (along with other ITS applications) require infrastructure-based communications, it makes sense to also utilize these DSRC signals to aid in positioning. Similarly, a DSRC & GNSS aiding kinematic integrated approach will likely be viable. As future DSRC communication systems are being added to the roadway infrastructure to allow for the exchange of information between vehicles, and between vehicles and infrastructure, then it makes perfect sense to possibly use these new communication signals for positioning.

BIBLIOGRAPHY


