Integrated Cooperative Localization for Connected Vehicles in Urban Canyons

Mariam Elazab*, Aboelmagd Noureldin‡ and Hossam S. Hassanein°
*Electrical and Computer Eng. Dept., Queen's University, Canada, mariam.el.azab@queensu.ca
‡Electrical and Computer Eng. Dept., Royal Military College of Canada, Canada, aboelmagd.noureldin@rmc.ca
°School of Computing, Queen's University, Canada, hossam@cs.queensu.ca

***Abstract*— The goal to achieve accurate and ubiquitous localization is the driving force for location based services in vehicular ad hoc networks (VANETs). In urban areas, global positioning system (GPS) and in-vehicle navigation sensors (e.g. odometers) suffer from prolonged outages and unsustainable error accumulation, respectively. The need for precise vehicle localization remains paramount, and cooperative vehicle localization based on ranging techniques are being exploited to this end. This paper presents a novel cooperative localization scheme that utilizes round trip time (RTT) for inter-vehicle distance calculation, integrated with inertial sensor measurements to update the position of not only the vehicle to be localized, but its neighbors as well. We adopted the extended Kalman filter (EKF), to limit the effect of errors in both the sensors and the neighbors' positions, in computing the new location. In comparison to the existing cooperative localization techniques, our proposed cooperative scheme does not depend on GPS updates for the neighbors' positions thus making it far more suitable in urban canyons and tunnels. In addition, our scheme considers updating the neighbors' positions using their current inertial sensor measurements resulting in; better position estimation. The scheme is implemented and tested using the network simulator 3 (ns-3), vehicle traces are generated using SUMO and error models are introduced to the sensors and initial positions for different velocities and densities. Results show that our scheme outperforms the inertial navigation systems (INS) technology typically used in environments where GPS fails.**

***Keywords*— Cooperative Localization, VANETs, GPS Free, Kalman Filter, Inertial Navigation Systems, RTT.**

I. Introduction

Location based services and applications in vehicular environments are experiencing rapid development including safety monitoring, traffic and resource management [1]. Moreover, they have been extended to cooperative forms such as collision warning and cruise control [2, 3] utilizing the dedicated short range communication (DSRC) [4] and governed by the physical and MAC protocols defined in wireless access in vehicular environments (WAVE) in IEEE 802.11p.

Such developments necessitate precise pervasive localization of vehicles. Global navigation satellite systems (GNSS) such as GPS provide location with high accuracy ranging from 1 to 5 m. However, this level is not guaranteed in urban canyons [5] where the satellite signals experience excessive multipath due to high-rise buildings. Moreover, this signal requires open sky access, which is unavailable in tunnels. These outages can be controlled by integrating the GNSS with other navigation systems such as WLAN [6], RFID [7], or inertial navigation systems (INS) [8]. However, in GPS-free environments, typically tunnels and urban canyons, the above conventional integrations are suboptimal because of the extra cost required for deploying reliable infrastructures such as RFID and WLANs or due to the INS error accumulation in case of protracted GPS outages. Accordingly, VANETs cooperative localization is thoroughly addressed to achieve the anticipated accuracy [5].

Vehicular cooperative localization exploits the DSRC capability and allows vehicles to update their positions using both: positions of their surrounding neighboring vehicles and, the measured inter-vehicle distance using ranging techniques. Some neighboring vehicles can obtain position updates only during partial access to GPS or in the existence of nearby landmarks with known positions. In this case, these vehicles can broadcast their positions and act as mobile anchors to the other surrounding vehicles with unknown positions (denoted as vehicles to be localized). Afterwards, a ranging technique can be used such as received signal strength (RSS), time of arrival (ToA) or round trip time (RTT) to estimate the distance between the vehicles to be localized and their surrounding neighbors.

Both cooperative information (i.e. neighbor positions and distances) are subjected to different sources of errors, the localization technique for the neighbor position update and the ranging method. Therefore, the main challenges for a reliable and accurate cooperative localization are: 1) choosing the localization scheme and the ranging technique suitable for the environment, 2) mitigating the associated errors in both location and range, and 3) selecting the data fusion method for integrating the above mentioned data.

A. Related Work

Our main focus is on cooperative localization for urban canyons and tunnels. Thus, cooperative schemes that rely on GPS to update neighbors' positions [9] or enhance the GPS signal with cooperative information [10] are inapplicable and requires large computations. On the other hand, cooperative GPS-free localization in [11, 12, and 13] are applicable to our considered scenario. In [11], signal strength is used to estimate the distance between vehicles. Then, extended Kaman filter uses the measured distance in addition to the kinematic motion model and road map to update the current vehicle's position. Similarly, the authors in [13] have considered the noise and interference associated with the received signal strength for better distance estimation from the RSS. However, such RSS based ranging will suffer from limited performance due to its sensitivity to the used path loss model that relates the distance to the RSS [14]. This path loss model varies from one environment to another and requires burden calibration. In another study, time of arrival (ToA) was used in [12] to estimate the inter-vehicle distance and then fused with kinematic model through extended Kalman filter.

B. Aim, Contributions and Paper Organization

The aim of this paper is to introduce a VANET distributed cooperative localization scheme for use in urban canyons and tunnels where there is complete GPS blockage and localization based infrastructure is infeasible. Accordingly, only on-board vehicle sensors and inter-vehicle communication are used to update the vehicles' positions throughout their trajectory.

Our proposed cooperative localization scheme uses the RTT ranging technique integrated with INS technology to update the neighbors' positions during GPS outages. RTT does not require synchronization since the same vehicle will be calculating the difference between the time of transmission and reception. Moreover, RTT is proven to be robust to the channel for measuring inter-vehicle distances [15]. The final accurate position is then estimated by adopting linearized extended Kalman filter (EKF) which fuses the above data with the recent position of the vehicle to be localized (obtained from INS).

The paper is organized as follows: Section II provides an overview for the implemented distributed cooperative scheme. Section III introduces the detailed implementation of the system modules. Performance evaluation is then provided in Section IV. Finally, Section V concludes the paper and provides future work.

II. System Overview

A. Preliminaries

We assume that all vehicles have initial positions obtained either from GPS or any other localization system as in [11]. Then, these vehicles travel in urban areas where GPS is unavailable due to excessive multipath from large buildings or complete blockage as in tunnels.

Vehicles are equipped with DSRC transceivers, so each vehicle to be localized can communicate with its neighboring vehicles in the communication range via IEEE 802.11p. The neighbors in range are the vehicles that receive messages from the vehicle to be localized with power greater than certain threshold (referred as receiver's sensitivity).

The vehicles are also equipped with inertial navigation sensors: speedometers/odometers that measure the horizontal speed and, the gyroscope that determines the heading of the vehicle. We define the following system entities:

- *Sender* is the vehicle to be localized that sends messages to the surrounding vehicles acquiring information for localization.
- *Neighbor* is the vehicle within the communication range of the sender vehicle that receives the messages and then replies back with its information.

B. Scheme Overview

The proposed distributed cooperative localization scheme can be illustrated in the following main steps:

- The sender vehicle updates its position using the RISS mechanization.
- Sender vehicle then broadcasts location request messages (LRM) for collecting neighbors' navigation information (both location and sensor measurements).
- The received outdated neighbors' positions are corrected at the sender by applying RISS mechanization using their reported sensor measurements.
- The Euclidean distance d_{est} is computed which is a function of the updated neighbors' and the sender's positions.
- Round trip time (RTT) is calculated at the sender and used to measure the actual distance d_m between the sender vehicle and the neighbor responded to the broadcasted messages.
- Extended Kalman filter uses the calculated distances d_{est} and d_m to estimate the error in x and y positions of the sender vehicle.
- The estimated error is then used to update the sender's position.

These steps are summarized in the block diagram in Fig. 1.

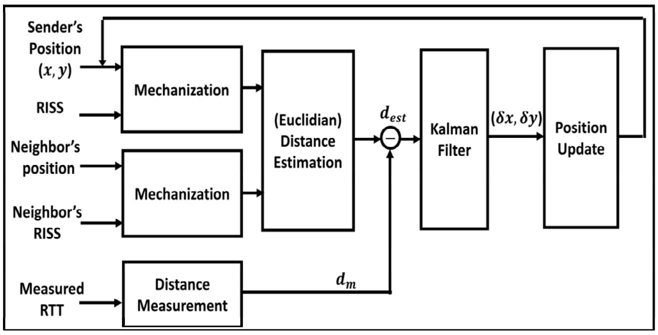

Fig. 1 Overview Block Diagram of the Proposed Cooperative Scheme

III. Cooperative Localization Scheme

The proposed cooperative localization scheme is illustrated in Fig. 2 and its details are described next.

A. Localization Request Messages (LRM)

Each sender vehicle to be localized requests neighbors' navigation information (positions, heading and velocities) through broadcast messages. The broadcast message contains both the ID of the vehicle to be localized denoted as sender ID and time of transmission T_{TX}.

All messages are broadcasted in the DSRC range every τ seconds. The neighboring vehicle in the communication range that receives the message with power greater than its sensitivity level $\hat{P}$ will add its navigation information (latest positions, current heading and speedometer readings) to the message and rebroadcasts the message. The latest position of the neighbor might be outdated by the time it is reported and thus it is accompanied with the above inertial sensor readings.

Once the vehicle to be localized receives back the neighbor's message, it checks whether the received message is a reply to its own broadcasted LRM or not. This is done by comparing its ID with the one appended in the reply message of the sender ID. If the IDs are identical, the message is decoded, otherwise it is ignored. The sender measures the time of reception of the LRM T_{RX}. Thus the LRM message contains the following information:

- Time of transmission of LRM T_{TX} used to measure the inter-vehicle distance $d_m^{(n)}$ using RTT.

- Neighbor's position denoted by its coordinates $x^{(n)}$ and $y^{(n)}$ where n is the neighbor's index. This position is the last updated available one at the neighbor which might be outdated from the current time of LRM reception. Accordingly neighbor's velocity and heading are also broadcasted.
- Neighbor's velocities in both x and y directions respectively denoted as $v_x^{(n)}$ and $v_y^{(n)}$, obtained from the odometer. Similarly, the neighbor's heading denoted as $A^{(n)}$ which is obtained from the gyroscope.

The above neighbor's information is used to update the received neighbor's position using RISS mechanization to estimate the Euclidean distance $d_{est}^{(n)}$ between the vehicle to be localized and neighbor n. Both distances $d_m^{(n)}$ and $d_{est}^{(n)}$ will be described and used afterwards to update the current sender vehicle's position.

B. 2D RISS Based Neighbors and Sender Position Update

In our proposed cooperative scheme, it was assumed that all vehicles have no GPS location updates as they travel in urban areas. Therefore as mentioned earlier, the neighbor reports in the LRM its last updated position which may be outdated at the time of the localization of the sender.

2D reduced inertial sensor system (2D-RISS) [8] is used instead to update the positions of both the vehicle to be localized and its neighbors. This is done at lower cost compared to full inertial navigation systems INS as the former consists of only two sensors: odometer (or speedometer) and gyroscope. The information from both sensors are used to compute the velocities in the east V_E and north directions V_N and then, calculates the displacement in the corresponding directions east and north equivalent to x and y positions respectively. Below are the main equations used in the 2D RISS as in [16].

$$\dot{A} = w_z \tag{1}$$

$$\begin{pmatrix} V_E \\ V_N \end{pmatrix} = \begin{pmatrix} V_{od}\sin(A_t) \\ V_{od}\cos(A_t) \end{pmatrix} \tag{2}$$

$$\dot{r} = \begin{pmatrix} \dot{\phi} \\ \dot{\lambda} \end{pmatrix} = \begin{pmatrix} 0 & \dfrac{1}{R+h} \\ \dfrac{1}{(R+h)\cos\phi} & 0 \end{pmatrix} \begin{pmatrix} V_E \\ V_N \end{pmatrix} \tag{3}$$

Where:

- w_z is the angular rate measured by the gyroscope.
- V_{od} is the vehicle's horizontal speed measured by the odometer.
- V_E and V_N are the east and north velocities, respectively.
- $\dot{\phi}$ and $\dot{\lambda}$ are the rate of change in latitude and longitude, respectively.
- $\dot{A}$ is the rate of change in azimuth (heading angle).
- R and h are the radius of earth and altitude, respectively.
- A_t is the current azimuth (heading angle) of the vehicle.

To ensure the robustness of our scheme, errors are introduced to both the INS sensors and the initial positions and modeled as normally distributed random variables. The error in odometer/speedometer readings follows Gaussian distribution with 0 mean and standard deviation equal to 10% from the speed of the vehicle as simulated in [7] and [17]. Thus, the increase in the odometer error is proportional to the distance traveled by the vehicle [18]. For the gyroscope, the error introduced is the angular random walk (ARW) that follows also Gaussian distribution with mean 0 and standard deviation chosen to be equal to $2°/\sqrt{hr}$ for a specific model according to [16]. After updating both the sender and the neighbors' positions using RISS, two distances are computed as described in the next sub-section.

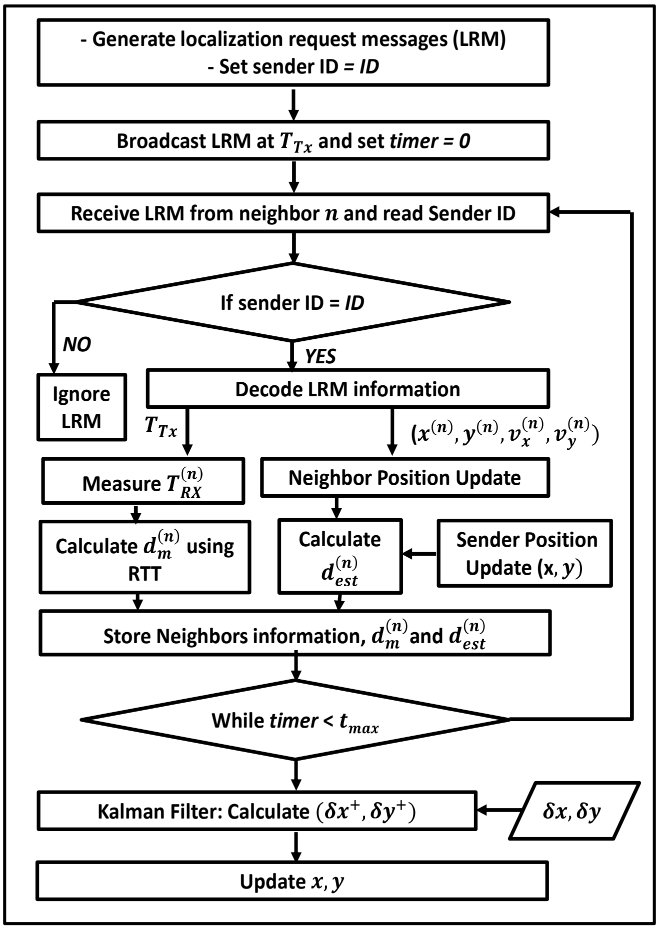

Fig. 2 Flow Chart of the Proposed Cooperative Scheme

C. Distance Calculation (d_{est} and d_m)

Based on the collected information, localization techniques such as multilateration can be applied to obtain an updated position for the vehicle to be localized. However, associated errors in these measurements will provide inaccurate position estimation when applying multilateration directly. Instead, linearized extended Kalman filter is used to obtain an accurate position update [8]. This linearized model relates the error in the current position to the error between both the two distances (i.e. the one measured using RTT and the one estimated using vehicles' positions).

The proposed cooperative scheme calculates two values of distances between the sender vehicle and each neighbor. The first distance denoted as $d_{est}^{(n)}$ and calculated based on the vehicles' latest positions as depicted in the equation below. It is the Euclidean distance between the RISS based updated position of neighbor n and the sender as computed from the previous sub-section. Thus, this distance is subjected to errors that are associated with odometer, gyroscope and the vehicles' positions.

$$d_{est}^{(n)} = \sqrt{(x^{(n)} - x)^2 + (y^{(n)} - y)^2} \tag{4}$$

Where:

- $x^{(n)}$ and $y^{(n)}$ is the RISS mechanization based updated position of neighbor n.
- x and y is the latest position of the sender vehicle (after RISS mechanization).

The second distance denoted as $d_m^{(n)}$ is calculated using the ranging technique RTT as shown below using the difference between transmission and reception T_{TX} and T_{RX} of the LRM at the sender. No error was introduced to the RTT as the delay offset that is generated from the processing can be statistically modelled and compensated in the calculations [19, 20]. Thus multipath and fading effects can be mitigated as in [21]. Thus, $d_m^{(n)}$ reflects the actual distance between the sender vehicle and the neighbor n.

$$RTT^{(n)} = T_{RX}^{(n)} - T_{TX} \tag{5}$$

$$d_m^{(n)} = \frac{c \times RTT^{(n)}}{2} \tag{6}$$

Where:

- $RTT^{(n)}$ is the time duration between transmitting the LRM by the vehicle to be localized and receiving the reply from neighbor n.
- c is the constant speed of light.

The error difference between the above two distances ($d_{est}^{(n)}$ and $d_m^{(n)}$) is used by Kalman filter described below to calculate the error to be added to the x and y position of the vehicle to be localized.

D. Kalman Filter

As discussed earlier, the Euclidean distance has many sources of errors and noises associated with the measurements. In order to obtain accurate estimation of the current vehicle's position in the presence of such errors, extended Kalman filter (EKF) is used. As such, KF is the best linear estimator when the error follows a Gaussian distribution [8] which is the case in sensor measurements and vehicles' positions. Typically, KF models the system dynamics as well as the measurements using linearized models which is not the case in distance based position estimation. Thus, our usage of KF works with errors in both: distances and positions (rather than the actual position and distances) to reserve its linearity. The conventional KF is utilized in this paper and consists of two stages: Prediction and measurement phases [8]. The measurement vector $Z_{t_{N\times1}}$ and the corresponding design matrix $H_{t_{N\times2}}$ are given in Eq. 7 and Eq. 8. Then, the estimated errors vector is used to correct the latest position of the vehicle to be localized according to Eq. 9.

$$Z_{t_{N\times1}} = \begin{pmatrix} d_m^1 - d_{est}^1 \\ \vdots \\ d_m^N - d_{est}^N \end{pmatrix} \tag{7}$$

$$H_{t_{N\times2}} = \begin{pmatrix} \frac{(x - x^{(1)})}{d_{est}^{(1)}} & \frac{(y - y^{(1)})}{d_{est}^{(1)}} \\ \vdots & \vdots \\ \frac{(x - x^{(N)})}{d_{est}^{(N)}} & \frac{(y - y^{(N)})}{d_{est}^{(N)}} \end{pmatrix} \tag{8}$$

$$\begin{pmatrix} x_t \\ y_t \end{pmatrix} = \begin{pmatrix} \delta x_t^+ \\ \delta y_t^+ \end{pmatrix} + \begin{pmatrix} x_{t-1} \\ y_{t-1} \end{pmatrix} \tag{9}$$

Where:

- N is the total number of neighboring vehicles.
- t is the measurement time epoch.
- $(+)$ and $(-)$ are the superscript signs that define the predicted and corrected values respectively.
- $\begin{pmatrix} \delta x_t \\ \delta y_t \end{pmatrix}$ is the error state vector consists of the errors in both x and y position.

IV. Performance Evaluation

A. Simulation Settings

The vehicles' traces are generated using SUMO traffic simulator [22]. The road is divided into two lanes where vehicles are allowed to follow realistic mobility models as they are moving into two opposite directions. The length of each lane is equal to 300 m and the width is 3m per lane. The inter-vehicle distance is set to be around 3m. The total number of vehicles is 50 and divided equally between lanes. During each simulation scenario, the vehicles move with constant speed suitable for urban canyon areas. The constant speed is changed in each scenario from 3 to 11 m/s.

The proposed cooperative scheme is simulated using the WAVE module in the network simulator 3 (ns-3)[1]. All the vehicles implement both UDP echo client and UDP echo server applications where the first application is used to request location messages from the neighbors while the latter responds to the messages requested by the vehicles according to our scheme flow chart in Fig. 2. Location update interval is set to 1 second (i.e. packet generation rate = 1 s) for efficient spectrum utilization and avoiding network congestion. KF parameters are extensively tuned to reflect the variance in the measured distances and the process noise. All other physical parameters are summarized in Table I.

B. Simulation Results

The evaluation metric used in the simulation is the average root mean square error (RMSE) between the true position from SUMO and the obtained position from the used localization scheme. RMSE is averaged over all vehicles and used to compare the cooperative proposed cooperative scheme with the 2D-RISS since the latter is the typically used localization technique in urban canyons and tunnels. All the simulated scenarios consider errors in inertial sensors and/or initial positions and thus all results are averaged over 50 runs for statistical validation. Our introduced cooperative scheme will be written in short as CL-RISS-KF in this section.

[1] http://www.nsnam.org.

TABLE I

SIMULATION PARAMETERS

Parameter	***Value***
Propagation Loss Model	*Log distance*
Propagation Delay Model	*Constant speed*
Minimum Received Power	*-105 dBm*
Odometer Error	$\sim N(0,\ (0.1 \times speed)^2)$
Gyroscope Error	$\sim N(0, 4\,°/\sqrt{hr})$
Initial Position Error	$\sim N(0, 2.25)$
Kalman Filter Parameters	$F_{t-1} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$
	$G_{t-1} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix},\ W_{t-1} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$
	$P_0^+ = \begin{pmatrix} 0.01 & 0 \\ 0 & 0.01 \end{pmatrix}$
	$Q_{t-1} = \begin{pmatrix} 0.3 & 0 \\ 0 & 0.001 \end{pmatrix},\ R_t = I_{NxN}$

1. Evaluation of Odometer and Gyroscope Errors

In this evaluation, error is introduced to the odometer and the gyroscope according to the models in Table I. The proposed cooperative scheme is then compared with 2D-RISS for different velocities as shown in Fig. 3. The non-cooperative RISS suffers from rapid diversions from the true positions (RMSE increased dramatically) over time compared to the cooperative scheme. The enhancement in our proposed cooperative scheme is attributed to the frequent updates from the used ranging technique RTT and the RISS based enhanced neighbors' positions. The performance degradation in higher velocities is due to the increased error variance in the odometer according to the used model [17].

2. Evaluation of Initial Position Errors

Our evaluation scenario is extended by introducing an error in the initial position that follows Gaussian distribution with variance equal 2.25 as shown in Table I. This variance is suitable for capping the GPS position error below 5 m. The KF parameters require tuning based on the newly added source of error in the initial position. In particular, the initial value of P matrix in Table I was increased to reflect the uncertainty in the initial erroneous position. Practically, this value can be also obtained from the standalone positioning system used in obtaining the initial position of each vehicle. Similarly, the Q matrix entry that corresponds to the error in the y position is increased to compensate the error in the initial position compared to the ideal initial position scenario discussed previously with no error in the y position since the vehicle was moving only in straight line in the x direction.

Comparing the two schemes as shown in Fig. 4, the proposed cooperative scheme continues to outperform the 2D-RISS over the trajectory. From Fig. 4, the RMSE of both schemes increases initially because of the error in the initial position. The cooperative scheme was then able to correct the position using the ranging technique and the enhanced neighbors' positions. Thus, vehicles with low position error can improve the position of other vehicles with higher error using the measured distance. Conversely, such enhancement is not achievable in the RISS since each vehicle continues to deviate from the true position as a result of error accumulation.

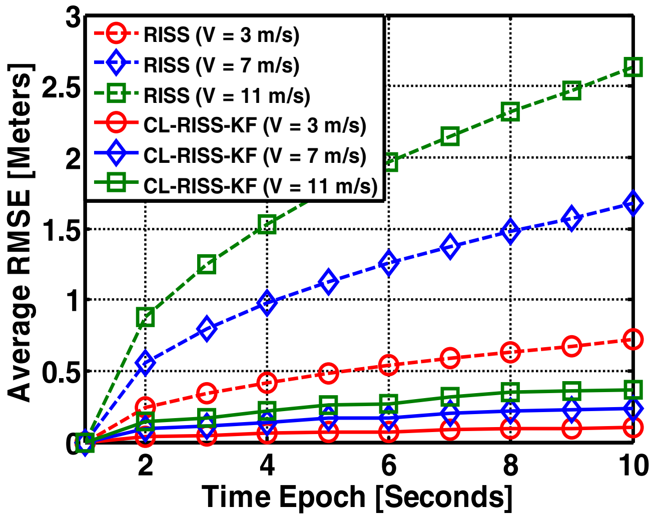

Fig. 3 Comparison between the Proposed Cooperative Scheme and 2D RISS with Sensor Errors

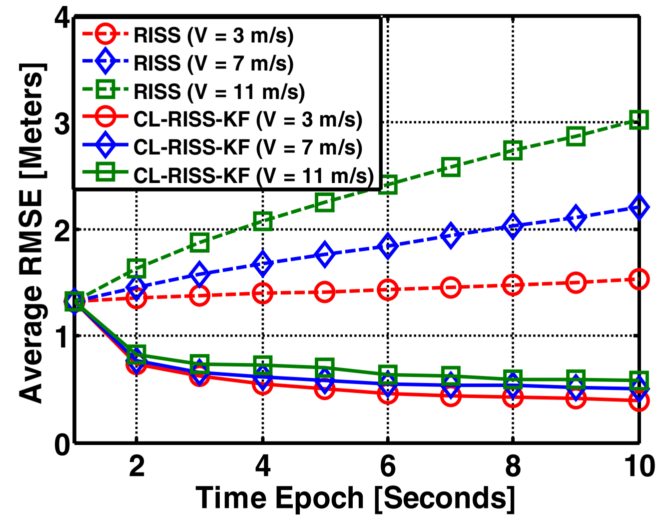

Fig. 4 Comparison between the Proposed Cooperative Scheme and 2D RISS with Error in Initial Position and Sensor Measurements

3. Evaluation at Different Neighbors Density

In the above scenarios, the sensitivity of all the vehicles was fixed at -105 dBm. This small value resulted in large communication range that allows cooperation between all the considered vehicles. In order to evaluate the effect of the neighbors' density on the performance of our localization scheme, the above sensitivity is increased to -95 and then to -85 dBm. Thus, less number of neighbors will receive and respond to the LRM. Practically, these effects can be achieved by decreasing the transmitted power. Fig. 5 shows the effect of power that reflects the number of neighbors used in the localization on the RMSE for the three different velocities with the presence of error in both the initial positions and the inertial sensors. At the initial time instant (worst case for our cooperative scenario in the existence of initial error), the average RMSE is compared to the average number of neighbors for the different velocities as in (a), (c) and (e). While in (b), (d) and (f), the minimum number of neighbors is compared to the corresponding maximum value of RMSE. From Fig. 5, RMSE increases when the total number of neighbors used in localization decreases and/or the velocity of vehicles increases.

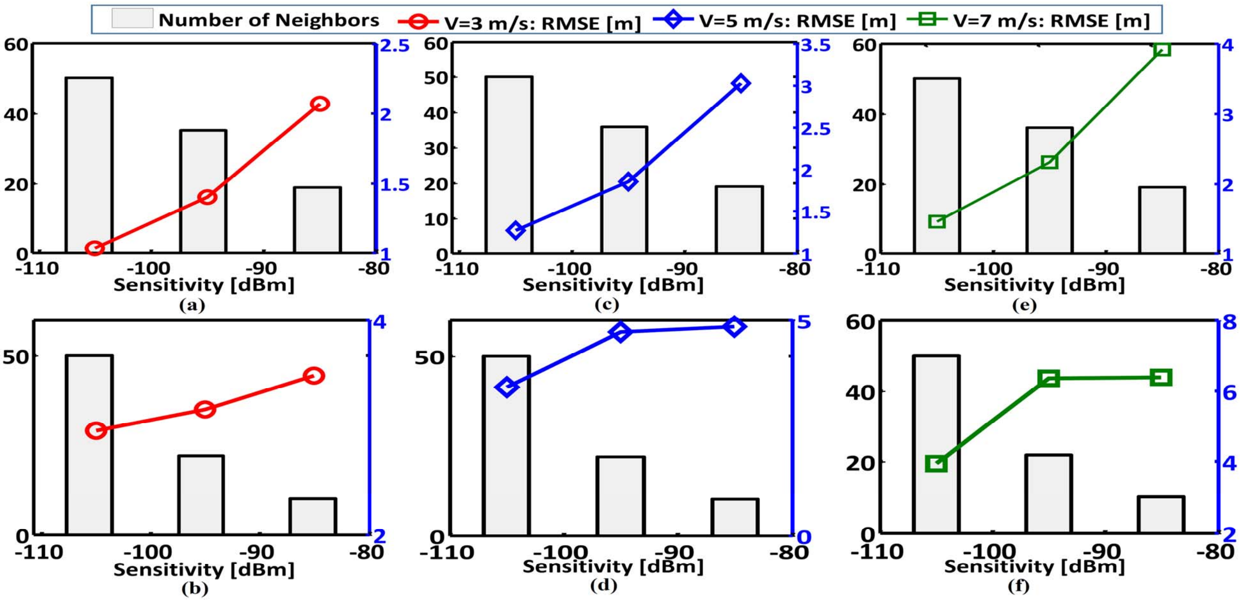

Fig. 5 Effect of Neighbors' Densities on Localization Accuracy of the Proposed Cooperative Scheme.
(a), (c) and (e): Average Values. (b), (d) and (f): Minimum Neighbors and Maximum RMSE.

V. CONCLUSION

In this paper, a new cooperative localization scheme for VANETs in GPS-less environments is introduced. The scheme uses RTT for measuring inter-vehicle distance, and relies on RISS for enhancing the position of the sender and the neighbors. These data are then fused using extended Kalman filter resulting in accurate position estimation in the presence of errors in inertial sensors and initial positions. Simulations show that the proposed scheme outperforms the RISS which is typically used in GPS-free environments. Such performance is guaranteed for different velocities, errors in sensor measurements and initial positions in addition to various vehicle densities. The above enhancement is attributed to the ability of the cooperative scheme to use the RTT measurements to prevent error accumulation of the inertial sensors over time. Out future work includes 1) error modelling for RISS in Kalman filter, and 2) evaluating the proposed scheme with practical measurements and against other relevant cooperative schemes.

REFERENCES

[1] R. Atawia, H. Abou-zeid, H. Hassanein, and A. Noureldin, "Robust resource allocation for predictive video streaming under channel uncertainty," in Proc. IEEE GLOBECOM, Dec 2014, pp. 4683–4688.

[2] A. Boukerche, H. A. Oliveira, E. F. Nakamura, and A. A. Loureiro, "Vehicular ad hoc networks: A new challenge for localization-based systems," Elsevier Computer Commun., vol. 31, no. 12, pp. 2838–2849, 2008.

[3] T. L.Willke, P. Tientrakool, and N. F. Maxemchuk, "A survey of inter-vehicle communication protocols and their applications," IEEE Commun. Surveys Tuts, vol. 11, no. 2, pp. 3–20, 2009.

[4] F. C. Commission, "Amendment of the commission rules regarding dedicated short-range communication service in the 5.850-5.925 ghz band," fcc 02-302. Technical report, FCC, Tech. Rep., 2002.

[5] N. Alam and A. G. Dempster, "Cooperative positioning for vehicular networks: facts and future," IEEE Trans. Intell. Transp. Syst., vol. 14, no. 4, pp. 1708–1717, 2013.

[6] C. H. Ou, "A roadside unit-based localization scheme for vehicular ad hoc networks," Int. J. Commun. Syst., vol. 27, no. 1, pp. 135–150, 2014.

[7] E. K. Lee, S. Y. Oh, and M. Gerla, "Rfid assisted vehicle positioning in vanets," Elsevier Perv. Mobile Comput., vol. 8, no. 2, pp. 167–179, 2012.

[8] N. Aboelmagd, T. B. Karmat, and J. Georgy, "Fundamentals of inertial navigation, satellite-based positioning and their integration," 2013.

[9] A. Mahmoud, A. Noureldin, and H. Hassanein, "Vanets positioning in urban environments: A novel cooperative approach," in Proc. IEEE VTC, 2015.

[10] N. Alam, A. T. Balaei, and A. G. Dempster, "A dsrc doppler-based cooperative positioning enhancement for vehicular networks with gps availability," IEEE Trans. Veh. Technol., vol. 60, no. 9, pp. 4462–4470, 2011.

[11] R. Parker, S. Valaee, "Cooperative Vehicle Position Estimation," in Proc. IEEE ICC, vol., no., pp.5837, 5842, 24-28 Jun. 2007.

[12] K. Golestan, S. Seifzadeh, M. Kamel, F. Karray, and F. Sattar, "Vehicle localization in vanets using data fusion and v2v communication," in Proc.ACM MSWiM, 2012, pp. 123–130.

[13] L. Altoaimy, I. Mahgoub, and M. Rathod, "Weighted localization in vehicular ad hoc networks using vehicle-to-vehicle communication," in Proc. IEEE GIIS, 2014, pp. 1–5.

[14] T. S. Rappaport, Wireless communications: principles and practice, 2002.

[15] H. Kloeden, D. Schwarz, E. M. Biebl, and R. H. Rasshofer, "Vehicle localization using cooperative rf-based landmarks," in Proc. IEEE IV Symp., 2011, pp. 387–392.

[16] J. Georgy, A. Noureldin, M. J. Korenberg, and M. M. Bayoumi, "Modeling the stochastic drift of a mems-based gyroscope in gyro/odometer/gps integrated navigation," IEEE Trans. Intell. Transp. Syst., vol. 11, no. 4, pp. 856–872, 2010.

[17] R. Fuller and X. D. Koutsoukos, Mobile Entity Localization and Tracking in GPS-less Environnments. Springer, 2009, vol. 5801.

[18] K. P. Valavanis "Applications of intelligent control to engineering systems Intelligent Systems, Control and Automation," Springer, 2009.

[19] A. Bahillo, J. Prieto, S. Mazuelas, R. M. Lorenzo, J. Blas, and P. Fernández, "Ieee 802.11 distance estimation based on rts/cts two-frame exchange mechanism," in Proc. IEEE VTC, 2009, pp. 1–5.

[20] M. Marchenko, A. Ramirez, and C. Schwingenschlögl, "Method for calibrating a propagation-time-based localization system," uS Patent 8,494,556, Jul. 23, 2013.

[21] B. Schaffer, G. Kalverkamp, and E. Biebl, "A 2.4 ghz high precision local positioning system based on cooperative roundtrip time of flight ranging," in Proc. VDE GeMIC, 2014, pp. 1–4.

[22] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, "Sumo–simulation of urban mobility," in SIMUL, 2011.