RF-GPS: RFID Assisted Localization in VANETs

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Abstract—**Providing vehicles' position is essential in VANETs. Currently, GPS positioning is widely used, but the accuracy is not adequate for emerging safety applications. In order to provide accurate positioning, this paper proposes RF-GPS, a RFID-assisted localization system that reliably supports lane-level position accuracy. It improves accuracy of the GPS system by employing a DGPS-like concept. It also allows vehicles without GPS to compute their position by contacting GPS equipped neighbors. We evaluate the performance of the proposed localization system via simulation.**

I. INTRODUCTION

In Vehicular Ad hoc Network (VANET), localization is becoming a critical necessity since many VANET applications require position data. GPS, despite showing errors up to tens of meters, has been widely used for VANET routing and navigation applications which generally tolerate such errors. However, safety and emergency applications, e.g., collision avoidance, demand highly accurate position data, i.e., lane-level accuracy within at least 3m.

Various localization schemes have been proposed to improve the accuracy. Most of them exploit signal propagation properties, e.g., Received Signal Strength Indicator (RSSI) and Time of Arrival (ToA). For example, cellular localization [18] uses the propagation delay of the signals from transmit towers to calculate the "absolute" position. The main challenge in absolute positioning is the unstable wireless channel, e.g., distortion and interference. Ad hoc network localization uses the propagation properties to estimate distance between neighbor vehicles [13] and thus finds "relative" positions. But, trilateration, a relative positioning technique, requires at least 3 neighbors within the radio range to directly determine the position. So, it cannot work in sparse traffic environments. Data fusion calculates vehicle's position by integrating several data points from different sources, e.g., GPS and camera [6], [16]. But, position accuracy entirely relies on the number and quality of attached sensors, and pre-training may be required for better performance. The GPS error correction is distributed over the Internet [2], but a moving vehicle can make use of it only when a low latency connection to the Internet is available. Among existing schemes, DGPS (Differential GPS) improves position accuracy to the level of tens of centimeters in the best cases [9]. Its accuracy, however, gets worse for vehicles far away from the reference node. An excellent survey on VANET localization can be found in [6].

In order to provide accurate positioning in VANET, this paper introduces Radio-Frequency Identification (RFID) and proposes a RFID-assisted localization system. The system employs DGPS concept to improve GPS accuracy. A GPS vehicle obtains exact position data from a RFID tag on the roadside unit while traveling. Then, it calculates GPS error from own GPS measurements and RFID position data and broadcasts the error to neighbor vehicles via IEEE 802.11 radio. Non-GPS vehicles find their position by a single peer localization scheme in the system. When a Non-GPS vehicle encounters a vehicle with accurate position data, they exchange position and travel information via RFID and IEEE 802.11 radio respectively. Then, the Non-GPS vehicle computes accurate position from the received data.

Our primary contribution is the design of a novel accurate localization system that depends on neither signal strength nor propagation properties. Moreover, a Non-GPS vehicle can determine accurate position from a single vehicle encounter. To prove feasibility, we investigate the various parameters of the RFID technology and analyze their impact on accurate positioning in VANET. Simulation results show that RFID-assisted localization provides sufficient accuracy for most vehicular applications.

The rest of the paper is organized as follows. In Section II, we review vehicular applications requiring accurate localization. We also review two prior VANET localization schemes. Section III discusses RFID technology and RFID-enabled vehicular applications. Section IV presents the proposed localization system. Its evaluation is studied with experimental results in Section V. Section VI concludes the paper.

II. ACCURATE LOCALIZATION

A. Safety Applications

Safe "assisted" driving can be achieved only with precise vehicle position knowledge. An enhancement of situation awareness gives a driver a clearer view of hidden vehicles, road condition, and other obstacles, even in severe weather [8]. If vehicles' positions are shared with neighbors, one can detect approaching vehicles, and thus avoid an unsafe lane change or turn, for example. *Collision avoidance* in urban intersections is a textbook application [11]. A driver entering the 4-way intersection may miss a vehicle entering the intersection from the right and engaging in a left turn. In poor visibility (e.g., foggy night), this can easily lead to an accident. If both drivers detect the potential danger by exchanging accurate position information, the accident can be avoided. When an accident has already occurred, a post accident management provision warns nearby vehicles of the emergency situation [6]. If a

vehicle is informed of accurate position of the accident, it can automatically initiate emergency breaking and stop safely. This also avoids pile-up collisions of following vehicles. However, since GPS error on roads is 10m~20m today [15], it cannot satisfy the accuracy requirements of those applications. Thus, more accurate localization is needed.

B. Differential GPS and Dead Reckoning

One solution for accurate localization is DGPS. The distance between the satellites and the GPS receivers is so large that GPS receivers within the same area have almost the same signal propagation delay, and thus the same GPS error. Once a differential value, i.e., GPS error, is computed in one GPS receiver, it can be used to calibrate all the nearby GPS receivers. DGPS has been used for marine navigation, where a reference node that has exact position is placed near the coast line. The reference node computes GPS error by comparing the GPS data received from satellites with its own exact location. Then, messages including GPS error are transmitted to ships passing nearby so that they can correct their GPS coordinates. Since there are no obstacles distorting GPS signals in the sea, the reference node and nearby ships have the same GPS error. Thus DGPS enables to find the accurate position. In a urban area, however, tall buildings cause fluctuation in GPS errors so that each block has different GPS error rate even within small areas. Therefore, DGPS fails to provide accurate position data. This problem combined with the high DGPS cost has limited its deployment in urban areas.

Dead Reckoning (DR) is another enhancement technique for GPS devices [12]. When a GPS signal is temporarily unavailable, a mobile node estimates its current position based on its last measured GPS location and its motion parameters, e.g., speed, orientation, and time. Vehicular applications employ DR to maintain localization in places where the GPS signal cannot be received, e.g., tunnels, indoor parking lots, etc. DR guarantees accurate position only for a short time, however, since estimation errors quickly accumulate. The error depends on accuracy of on-board speed and orientation sensors. As a term of comparison, a speedometer has an error range of around $\pm 3 \sim \pm 10\%$ and a digital compass or a gyroscope has $10°/sec$ of orientation error at maximum.

III. RFID AND VEHICULAR APPLICATION

RFID system transmits an object identity using electromagnetic waves. In the passive RFID system, an RFID tag stores its ID in memory. The RFID reader emits RF radio waves eliciting a signal back from the tag. More precisely, upon receiving the radio waves, the tag absorbs energy and pumps back the waves modulated with its own ID signature. RFID operates in various frequency bands and corresponding radio ranges. Many applications use passive RFID tags in Ultra High Frequency (UHF, 860MHz~2.45GHz) because of low cost (less than 10 cents) and relatively long radio range (up to approximately 10m). The most important benefit of an RFID tag is the battery-free operation. A tag works without a power source since it gathers energy from a reader's waves. With

tiny memory, the size of a tag chip can be reduced to a size of 0.4mm square [3]. Low cost makes it attractive to deploy passive RFIDs on the road for VANET applications.

RFID is indeed used in various vehicular applications. For instance, in the Automatic Toll Collection (ATC) system, roadside RFID readers identify passing vehicles by reading tags on them and then automatically charge the fare. Iftode et al. in [10] proposed the lane reservation system, where only drivers with valid reservation can drive on the high-priority lane. The enforcement system with RFID readers on roadside units detects violators by reading their RFID tags. In the Road Beacon System (RBS), the RFID reader on a vehicle gets road information from RFID tags buried in the pavement [4]. An RFID-based accurate positioning system for vehicles was proposed in [7] and [11]. A vehicle with RFID reader updates its position by passing over the RFID tags that store accurate position and are attached to the road surface. Other RFID based vehicular applications can be found in [8] and [14].

IV. RFID-ASSISTED LOCALIZATION SYSTEM

A. Preliminary

We assume that vehicles are able to communicate with each other via both IEEE 802.11 and RFID. A vehicle broadcasts packets to one-hop neighbors using IEEE 802.11 radio. At the same time, it exchanges data with neighbors using *mobile RFID tag/reader set*. In our model, only a fraction of vehicles has GPS receivers, while all vehicles have an RFID tag/reader set (or at least all those vehicles that wish to maintain accurate positioning). The width of each lane is 3m. RFID tags are placed at selected roadside units, e.g., speed advisory signs. Fig. 1 depicts the proposed localization system in a freeway: RF-GPS with single peer localization. Terminology used in this paper is as follows:
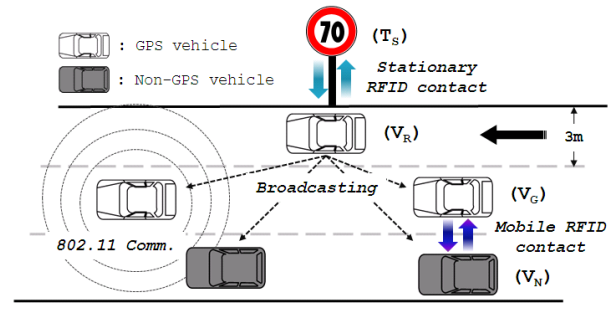

Fig. 1. The Proposed localization system: RF-DGPS and Single Peer Localization.

- *Stationary RFID tag* is a 4m radio range passive tag affixed to a roadside unit. It stores accurate position data and transmits it to passing vehicles.
- *Mobile RFID tag* is a semi-passive tag attached to each vehicle. It stores and sends vehicle's ID to neighbors in response to their interrogations.
- *Mobile RFID reader* is an interrogator on a vehicle that extracts data from either a stationary or mobile RFID tag.

- *Reference vehicle* is a GPS vehicle that has obtained accurate position data from a stationary RFID tag. It is a mobile version of a reference node. After calculating GPS error, it broadcasts GPS error via IEEE 802.11 radio.
- *GPS coords* is coordinate data obtained from a GPS receiver on the vehicle. *Abs(olute) coords* is coordinate data stored in a stationary RFID tag reporting the exact position. *Accurate coords* (Accurate position data) is a vehicle's position data within 3m error range. *Diff(erential) coords* is difference between a GPS coords and an Accurate coords in a vehicle. It represents a GPS error at the point.
- *Travel data* is information of a vehicle's movement; vehicle ID, Accurate coords, speed, and orientation.

B. RF-GPS

RF-GPS (RFID assisted GPS) improves GPS position accuracy by exploiting mobile reference nodes on the road. Unlike the traditional DGPS that uses a fixed reference node, RF-GPS designates a moving vehicle as a reference node. The vehicle passing by a roadside unit receives Absolute coords and calculates error rate using own GPS coords and received Abs coords. Then, it broadcasts GPS error (Diff coords) to neighbors to allow them to correct their GPS position.

1) Stationary RFID contact: Stationary RFID tags that store Abs coords in the memory are installed on roadside units. When a (Non-)GPS vehicle travels into the radio range of T_S, the mobile RFID reader on the vehicle obtains an Abs coords from T_S via RFID communication. Due to short radio range (3∼4m) of RFID communication, only vehicles traveling on the lane closest to the road divider (or to the curb) can read the Abs coords from T_S. Since the distance from the center of the lane to T_S is known, and so is the orientation of the tag with respect to the vehicle, the latter can easily calculate its Accurate coords from Abs coords. A GPS vehicle, then, calculates a Diff coords by subtracting the Accurate coords from its GPS coords. At this point, it is ready to be a reference vehicle (V_R in Fig. 1) such as a mobile DGPS reference, since the Diff coords represent the GPS error in that spot. Note that a Non-GPS vehicle cannot be a reference vehicle, since it does not have the GPS coords.

2) Broadcasting: The reference vehicle V_R now broadcasts the Diff coords to one-hop neighbors via the IEEE 802.11 radio. Since vehicles within radio range, say, on the freeway are highly likely to have the same GPS error, nearby GPS vehicles can calculate their Accurate coords using received Diff coords. However, Non-GPS vehicles (V_N) within the range cannot compute Accurate cords since they do not have own GPS coords.

C. Single Peer Localization

In the basic RF-GPS scheme, a Non-GPS vehicle can get accurate position only through the stationary RFID contact. To enhance positioning of Non-GPS vehicles, we propose a single peer localization scheme. When the Non-GPS vehicle encounters a GPS vehicle with Accurate coords, it establishes two wireless communication links; a mobile RFID contact and an IEEE 802.11 peer-to-peer link. Upon receiving data from the neighbor vehicle, the Non-GPS vehicle computes its accurate position.

1) Mobile RFID contact: When a Non-GPS vehicle (V_N) encounters a GPS vehicle (V_G), the V_N reads V_G's ID, ID_G; the mobile RFID reader on V_N accesses the mobile RFID tag on V_G. V_N also records the contact time T_M with ID_G for future calculation. Since V_N only obtains ID of V_G, it is possible that V_N contacts with wrong vehicles which are Non-GPS vehicles or GPS vehicles having no Accurate coords. To prevent this situation, V_N stores mobile RFID contact information, e.g., vehicle's ID and contact time, in the memory before they establish 802.11 peer-to-peer connection.

2) 802.11 Peer-to-Peer Connection: The mobile RFID contact triggers 802.11 peer-to-peer connection on V_G. Even though V_G does not obtain any information of the contacted vehicle from the mobile RFID contact, it knows that V_N is very close due to RFID radio range. Therefore, V_G broadcasts a message including its ID, accurate position, and travel data with reduced power to reduce signal interference. When V_N receives the message, it records the time T_S and acquires data tuple $\{ID'_G, (x_G, y_G), S_G, O_G\}$, which are ID, Accurate coords, speed, and orientation of V_G. Two ID data, ID_G and ID'_G, are used for authorization. V_N also takes its travel data $\{S_N, O_N\}$ into account in order to compute its Accurate coords (x_N, y_N). Let assume $\Delta T = T_S - T_M$, $\Delta O = O_G - O_N$, and ΔL = width of a lane. Then, x_N and y_N can be obtained by Equation (1). Finally, the Non-GPS vehicle obtains its accurate position data.

$$x_N = x_G + \Delta T * (S_G - S_N * \cos(\Delta O))$$
$$y_N = y_G - \Delta T * S_N * sin(\Delta O) - \Delta L \tag{1}$$

3) Dead-Reckoning: Dead-Reckoning is generally used by a GPS vehicle only in the absence of GPS signals, e.g., tunnel or indoor parking lot. For Non-GPS vehicles, on the other hand, DR is used all the time between RF contacts with GPS and roadside sources. Recall that Non-GPS vehicles have two chances to obtain accurate position data; stationary RFID on the roadside unit and single peer localization through GPS vehicles. Thus, Non-GPS interpolate these references with DR.

D. Position Accuracy

In this subsection, we evaluate RF-GPS and DR position accuracy. The enumerated accuracy values are used as criterion to evaluate the proposed system in Section V.

In marine navigation (Section II-B), DGPS works for a ship up to 300Km away from the reference. The U.S. Department of Transportation estimated error growth of 0.67m per 100km from the coast-line where the reference node is placed [5]. Obviously, we cannot expect the same accuracy in the vehicular scenario. As mentioned earlier, the accuracy relies on signal delay. Obstacles on the road affect GPS signal delays, and thus result in dissimilar GPS errors for different receivers even in a small area. In the urban area, the problem becomes even more severe since each block may have a different GPS error. The

"mobile DGPS" approach can provide accurate position data with distributed RFID tags and moving reference vehicles. The GPS error measured by the reference vehicle is broadcast only to nearby vehicles within 802.11 radio range and only for a short time. Thus, neighbor vehicles do not receive obsolete, erroneous position data. The accuracy of the mobile DGPS approach is strongly related to the accuracy of the measured GPS error. We can reduce this error by pervasive deployment of stationary RFID tags with Abs coords. In addition, traffic pattern also affects GPS error measurement.

Many researchers have evaluated and published GPS errors in the literature. Shengbo, et al. [17] show that the position estimation error in DR scheme is around 1%∼2% of travel distance. This means that around 20m of position error occurs in 30s at 100Km/h. The estimation error rate in a vehicular scenario, however, can be reduced because vehicles travel only along the roads and seldom turn their orientation sharply. Specifically, on a freeway, the estimation error rate decreases to 0.3% of travel distance [12]. In other words, there would be 2.5m estimation errors in 30s at 100Km/h. The error range (0.3%∼2%) tells a landmark for our study. Our targeting error range is 3m, the width of a single lane. At 100Km/h speed, 3m error occurs when traveling 150m and 1000m with 2% and 0.3% of estimation error rate, respectively. On the time line, we can say that the position data estimated by DR lasts for 5.39s and 35.97s, with 2% and 0.3% of estimation error rate, respectively. At 60Km/h, similarly, an accurate position data should be renewed every 8.98s and 59.88s for 2% and 0.3% of estimation error rate. On a freeway, vehicles travel fast but they hardly turn their orientation abruptly, which cuts down the estimation error. In an urban street, on the other hand, frequent orientation changes happen. However it is expected that the average speed would be less than 60Km/h, which cuts down the estimation error, too. We account for these conditions in our experimental evaluation. For example, our experiment monitors how often vehicles can update their position and we compare the measured update intervals with our threshold values, *36s* and *60s*.

V. Evaluation

In this section, we validate RF-GPS using Qualnet, a packet level network simulator. We implement RF-GPS and design a 4-lane freeway scenario in which all vehicles move in one direction with various speeds. Vehicles have 4m range RFID system and 250m range IEEE 802.11 radio. Table I describes default values of scenario parameters. Experiments in the paper use default values unless explicitly stated. We measure the latency until a vehicle acquires the first accurate position data. The experiment tells us the ability of RF-GPS to guarantee accurate positioning in representative traffic conditions. The interval between position acquisition by Non-GPS vehicles is also measured to assess the ability to support such users. More generally, we evaluate RF-GPS performance for various system parameters.

To evaluate the proposed localization system, we design four different scenarios. First, we run simulation with different

| Scenario Parameter	Default Value
Number of vehicles	200
Percentage of Non-GPS vehicles	50%
Speed range of vehicles	20∼30m/s
Interval of stationary RFID tag	5Km

TABLE I
SCENARIO PARAMETERS

traffic volumes on the road. The total number of vehicles on the road is an important factor since cars interact with each other to find accurate position. The fewer the vehicles, the fewer the reference points are. Thus, if there are not enough vehicles driving on the road, the probability of receiving the Diff coords decreases. This also degrades the possibility that Non-GPS vehicles encounter GPS vehicles having accurate position. Next, we change the percentage of GPS vehicles on the road. This value is especially critical to Non-GPS vehicles. If the numbers of GPS vehicles decreases, Non-GPS vehicles have less chances to obtain travel data via the single peer localization scheme. Thus, we arrange different fractions of GPS vehicles in our simulations. Third, we run simulations with different speed ranges. Speed difference between vehicles increases the chances of encountering other vehicles, and thus increases RFID contact rate. Last, we vary fraction of RFID-enabled vehicles on the road. More RFID capability on the road implies more reference vehicles which improves position accuracy of nearby GPS vehicles. The impact of RFID penetration on localization performance will be evaluated. Moreover, this will show that RF-GPS complements estimation error of the DR scheme when a GPS vehicle travels in a GPS deprived zone.
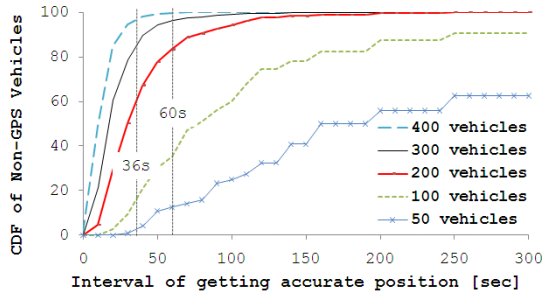
A. Traffic Volume

In this experiment, we deploy 50∼400 vehicles on a 5-Km-long 4-lane freeway. The average inter-vehicle distances are 50m∼400m, correspondingly. The results in Fig. 2(a) illustrates that the more vehicles on the road, the higher probability to obtain accurate position data. While the number of vehicles increases, the number of GPS vehicles that have accurate position increases and thus more Non-GPS vehicles can obtain accurate position via single peer localization. Fig. 2(b) demonstrates how often a Non-GPS vehicle renews accurate position data. 60.2% of Non-GPS vehicles can successfully renew their position data within 36 seconds in the case of 200 vehicles; the percentage of Non-GPS vehicles getting accurate position within 36 seconds jumps from 85.2% (300 vehicles) to 96.5% (400 vehicles). If we set the renew interval as 60s, higher than 83% of Non-GPS vehicles update accurate position within 60s when there are more than 200 vehicles on the road. This means that most Non-GPS vehicles keep maintaining their accurate position for most of time with 60s refresh interval via single point localization and Dead-Reckoning.

B. Fraction of Non-GPS Vehicle

In this experiment, we change the percentage of Non-GPS vehicles on the road. As shown in Fig. 3(a), as population of
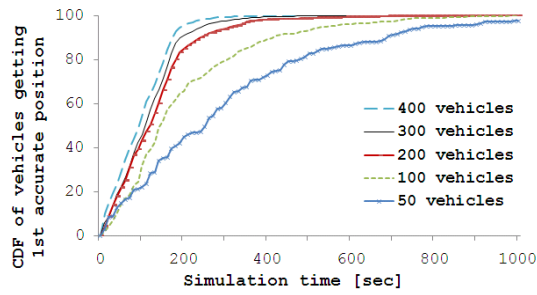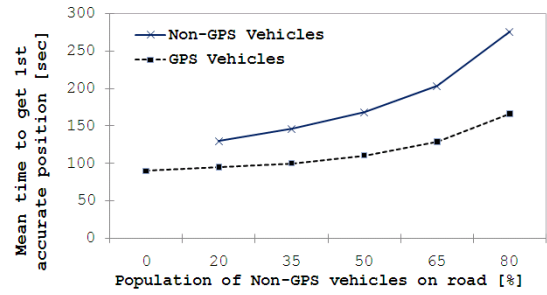
(a) Probability of getting accurate position

(b) Cumulative percentage of Non-GPS vehicles

Fig. 2.   Traffic volume.

(a) Probability of getting accurate position in GPS vehicles and Non-GPS vehicles

(b) Mean and median of renewing accurate position in a Non-GPS vehicle
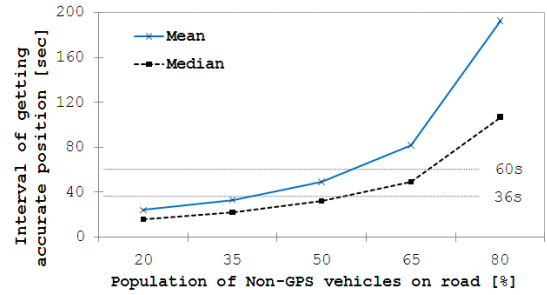
Fig. 3.   Fraction of Non-GPS vehicles.

Non-GPS vehicles grows, it takes more time for both GPS and Non-GPS vehicles to obtain accurate position data. If the number of GPS vehicles decreases, Non-GPS vehicles, in particular, have less opportunity to encounter GPS vehicles, to do single peer localization, and to obtain accurate position data. Non-GPS vehicle performance is more sensitive to change of the number of Non-GPS vehicles. Fig. 3(b) presents that update intervals of Non-GPS vehicles increase as its population on the road increases. When the populations are 20%, 35%, 50%, and 65% on the road, Non-GPS vehicles update their position within 60s in terms of median. However, a large portion of Non-GPS vehicles makes worse their own localization performance. As the percentage grows from 20% to 80%, the renew interval increases 8x in the mean and 6x in the median.

C. Impact of Speed Variables

This experiment measures how vehicles' speed impacts the localization performance. We divided speed ranges into three groups; 15∼30m/s, 20∼30m/s, and 25∼30m/s. Moreover, each group has two different lane-speed settings. In one setting, all the vehicles travel at a speed randomly selected from the given speed range. On the other hand, the other setting has faster lane and slower lane explicitly. The speed configuration is shown in Fig. 4(a). The lines show the speed ranges and the small rectangles in the middle of the lines are average speed values of vehicles. The bars represent standard deviation indicating speed variations. Fig. 4(b) exhibits the average renew interval of accurate position data in Non-GPS vehicles. High speed and large speed variation shorten the update interval of accurate position data. All Non-GPS vehicles can renew their accurate
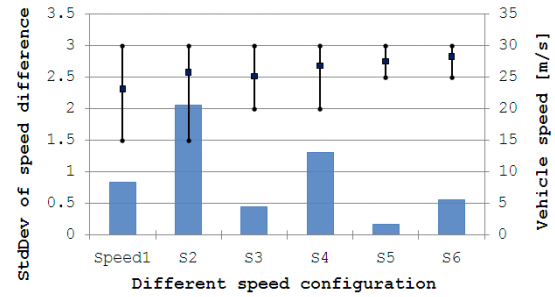
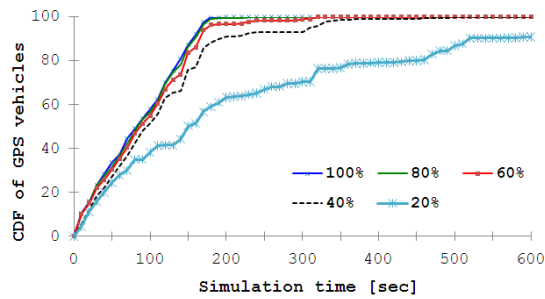(a) Speed configuration
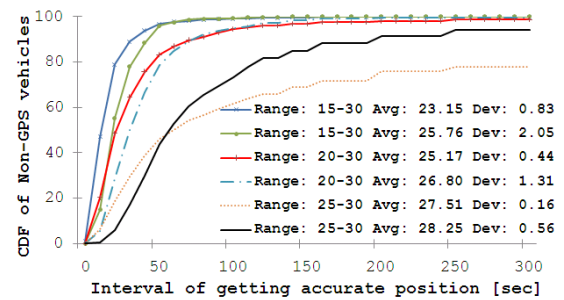
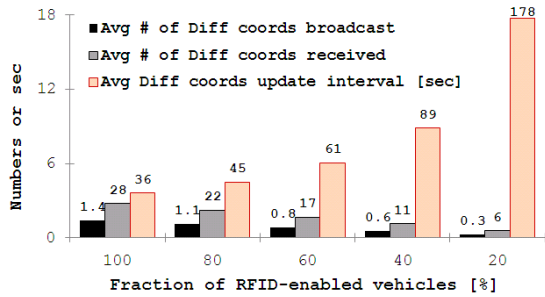(b) Cumulative percentage of Non-GPS vehicles

Fig. 4.   Speed variables.

position data within 60s in terms of the median values. This implies that Non-GPS vehicles aggressively take advantage of vehicles' speed variation to maintain accurate position.

(a) Probability of getting accurate position in GPS vehicles

(b) Messages on RF-GPS

Fig. 5.   Fraction of RFID-enabled vehicles.

D. Fraction of RFID-Enabled Vehicle

In this experiment, we assume all the vehicles have GPS and vary the fraction of RFID-enabled vehicles. Other parameters are same to Table I. In Fig. 5(a), as expected, the performance of the localization system rapidly degrades with decreasing numbers of RFID-enabled vehicles on the road. With 20% of RFID-enabled vehicles, performance 60 times worse as compared to the 100% RFID coverage at the worst case. This indicates that we need about 1/3 of RFID penetration to make a difference. Fig. 5(b) shows details. The average number of Diff coords broadcast and received increases with the RFID-enabled vehicles, almost proportionally. The update intervals of broadcasting Diff coords are also shown (the third bar in Fig. 5(b)). For instance, if 80% of vehicles is equipped with RFID, each GPS vehicle receives Diff coords and thus corrects GPS error every 45s. As mentioned earlier, GPS vehicles use DR scheme in the absence of GPS signal and can approximate the estimation error. However, DR errors become very severe in very long tunnels (say, several kilometers). Our results show that RF-GPS can maintain position accuracy even in the GPS deprived zones provided that there is sufficient RFID penetration. Properly deployed stationary RFID tags in the tunnel enable efficient updating of vehicles' positions.

VI. Conclusion

We presented a new localization system RF-GPS using RFID technology in VANET. It improves the accuracy of a GPS system by employing the Differential GPS concept along with the use of RFID reference points. The single peer localization helps Non-GPS vehicles or GPS vehicles whose GPS system is temporarily unavailable. We evaluated the proposed system via simulation. The results demonstrate that the system works well with representative road environments and show that Non-GPS vehicles successfully compute their accurate position.

The implementation of the proposed system in our Campus Vehicular Testbed (CVeT) [1] is part of our future plans. We will verify our system by comparing with state-of-the-art localization schemes. A numerical analysis of the accuracy of RF-GPS and of the corresponding performance of DGPS is also included.

VII. Acknowledgement

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