Smart Computing Review

Localization-Based System Challenges in Vehicular Ad Hoc Networks: Survey

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Abstract: The vehicular ad hoc network is an emerging technology providing quick and cost-efficient communications in the automobile industry and great applications providing safety, driver assistance and comfort. Real-time information about a vehicle node's position is based on assumptions acquired from various protocols and applications. One of the most popular technologies, the global positioning system (GPS), has been installed in vehicles to provide reasonable assumptions. A vehicular network depends on localization systems showing vehicle movement in critical areas. GPS systems have faced undesirable issues, such as information not always being available and not being robust enough for some applications. Different types of localization methods have been proposed, such as image/video localization, cellular localization and dead reckoning, to overcome GPS limitations. Data fusion for vehicle positioning is an emerging solution for robust and accurate techniques to replace previous techniques. In this paper, our discussion is based on localization requirements, localization applications and techniques, and the issues for vehicular ad hoc networks. Furthermore, we discuss how these localization techniques and data fusion are combined and used in safety applications to enhance network performance.

Keywords: Localization, global positioning system, cellular, data fusion

Introduction

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During the last couple of years, advances in embedded systems and wireless technologies have extended into new domains. Intelligent transportation systems are taking information and communications technology capabilities and advantages to stimulate vehicle networks into new types of vehicular ad hoc networks (VANETs) [1]. The main goal of a vehicular ad hoc network system is to enable efficient data distribution for drivers' and passengers' safety and comfort, and to protect them from danger [2]. Various attractive and wide-ranging potential applications have been visualized and facilitate travelers, such as collision detection, driver assistance, map location, accident detection, and internet access.

To make such applications possible, the network requires some sort of localization approach [3]. These approaches are used for finding accurate, real-time location discovery of vehicles, such as altitude, longitude, and latitude, which is a key component in application success. Global positioning system (GPS) receivers and digital compasses have been widely used for positioning and orientation services. Vehicle collision warning systems measure the distance from one vehicle node to an obstacle vehicle node's location and combine that with geographic information dissemination [4]. The emergence of communications with VANET technology is advancing towards more decisive applications. It is probable that a vigorous and extremely accessible localization system is required to provide quick and precise positioning services. A wide variety of positioning approaches have been proposed, such as cellular positioning, satellite positioning, and indoor positioning, etc. The global positioning system belongs to satellite positioning and has played a vital role in recent years. GPS receivers are cost-effective and convenient but not an efficient solution for obtaining a node's position information via satellite constellations. The GPS accuracy range starts from about 20 meters up to 30 meters, and they are not suitable for metropolitan high-density areas due to direct satellite invisibility. There are other various environmental factors that affect GPS services, such as line-of-sight signal obstruction, poor received-satellite conditions, and significant multipath interference. Because of these weak points, the global positioning system collective requires additional localization approaches for instant cellular localization, dead reckoning, and video/image localization, etc. The collection of these approaches and data acquired from several sources can be achieved with the help of data fusion methods like particle filters and the Kalman filter.

Accurate discovery is a key element for real-time location and successful outcomes for various applications in a network. GPS service has generally suffered from two major drawbacks. The first drawback is that GPS devices need perfect sight, and use a maximum of four satellites. This requirement is not suitable for indoor or downtown city centers that have obstacles (buildings) and for outdoor areas like deep valleys, etc. The second drawback is the inaccuracy of localization when vehicle nodes come near each other [5]. Various safety-critical applications have limitations in global positioning systems, especially where sub-meter accuracy is needed and they depend on the accuracy level for localization. A global positioning system cannot provide accuracy, even when the satellite signals are available.

The rest of this paper is structured as follows. Section 2 presents VANET applications and their requirements. Section 3 shows the different localization techniques and position computation through localization approaches. Section 4 elaborates on data fusion in localization and its related work.

VANET Applications

Vehicular applications have three major purposes: safety, efficiency, and service. Safety and efficiency applications are related to drivers in the system, and services are related to advantages of the newly devised and current systems. Developments in vehicular applications around the globe have been worked on and implemented in different projects, and capture users' interactions and intentions. These applications are initially compiled on the roads in transportation sectors, and the presence of many more companies is projected for future technologies. In these applications, information is disseminated and related to traffic conditions for control and improvement of vehicular and driver competencies.

For navigation and freeway traffic, the more significant thing is accuracy in applications that provide services to road users. For monitoring traffic, different solutions have been proposed, but installation, maintenance and limited coverage problems still exist. Traditionally, freeway systems are based on fixed sensors, such as loop detectors and television cameras, but these systems have limited coverage, are high in cost, and present maintenance difficulties. VANET applications are further divided into three categories: accurate localization plus highly accurate and inaccurate localization applications. Accurate localization applications contain real-time position information. Highly accurate applications refer to critical safety apps, which compensate for inaccurate info by computing position errors. The last category requires a certain degree of accuracy for distance estimation. Figure 1 shows different types of applications in a VANET. In the next section, we discuss these applications in detail.

■ Accurate Location-Aware Applications

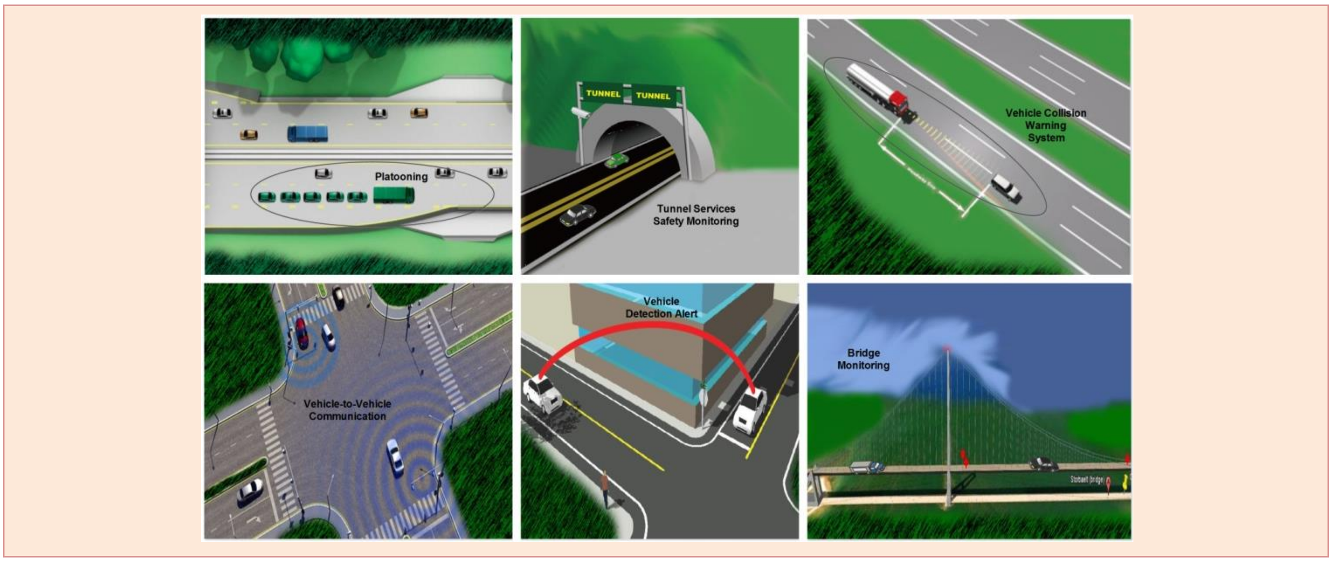

Figure 1. VANET Applications

Some applications require accuracy in the computed position information of vehicle nodes, and are usually used in cooperative driving applications. The vehicle nodes adopt partial control and exchange messages cooperatively for driving and sharing of space on the roads. We discuss these protocols and applications below.

Articles should be easy and understandable to the broad readers interested in smart computing. Thus, authors should follow the important editing instructions.

A. Cooperative Adaptive Cruise Control Applications

In these applications, the drivers set the vehicle speed and the system automatically controls the speed, especially when the vehicle is travelling uphill or downhill. These applications only deal with vehicle speed; the rest of the functions, such as direction, etc., are controlled by the driver. These systems contains a radar sensor for measuring the distance to other vehicles or the speed when no vehicle is behind. Adaptive cruise control (ACC) automatically adapts velocity and measures via radar or a scanning laser (e.g., light detecting and ranging, or LiDAR) [6]. Cooperative cruise control is an extension of ACC with a predecessor. The predecessor exchanges the messages through wireless communications.

B. Cooperative Intersection Safety Applications

Vehicles exchange messages when arriving at a road junction. Some junctions are without traffic lights, so for these blind crossings, the vehicles cooperate with each other for safe crossings. Localization accuracy is significant, because accuracy allows the recognition of lanes and sides of the street. Intersections are a serious main point for any accident in city areas. Various applications have been proposed for intersection safety in VANETs, such as the INTERSAFE project, which provides support to drivers in critical driving situations, especially intersections [7]. Accurate localization is needed to match detected objects with the static data of a high-level map. In this project, two different approaches are used: bottom and up. A laser scanner and video camera are used in vehicle-to-infrastructure (V2I) communications for object detection or detection of road markings.

C. Platooning Applications

Platooning applications are efficient for vehicle nodes travelling at the same speed but with minimum distance between them. In this technique, each vehicle follows a leader vehicle in the form of a row. Vehicles track the lead vehicle position with a good precision, accomplished with an accurate localization system. In platooning, the vehicles follow the lead vehicle with minimal inter-vehicle spacing [8]. Communications in a platoon vehicle are possible via 802.11p radio at 5.9 GHz so the vehicles can send messages for safety and to coordinate movement. The position of vehicles is very significant in the success and performance of these applications [9].

■ Inaccurate Location-aware Applications

Some VANET applications work with inaccurate, or in some cases without, localization information; but if localization information is available, then these applications perform better. These types of application use mostly vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) communications for things like road congestion, accident detection, information routing, etc. In accident detection applications, vehicles receive messages about accident locations to make time decisions (e.g., slow down or change lanes), and they make location-aware decisions accordingly [10]. Mostly, the protocols in VANETs accept 10- to 20-meter errors, but for long ranges, the vehicle transmitters compensate for localization errors. However, greater localization errors disturb protocol performance in the network. These errors can potentially affect the end-to-end packet delivery ratio [11].

Protocols with Localization

Various types of routing protocol use position information to send data between source and destination, and deal with a VANET's unique characteristics, such as highly changeable topology and high mobility. Position information in routing protocols have long been used and implemented in VANETs. Position-based routing protocols are suitable for data packet routing by considering the position of the destination [12]. These protocols work with GPS and navigation systems, which are most popular nowadays. Among the different approaches used inside these protocols, one of the most popular is the greedy forwarding approach [13, 14]. In it, the source sends the data packet to the nearest neighbor node, with destination and location information used at every step. Some other routing protocols in VANETs use maps and vehicle-movement information [15, 16]. Infrastructure networks also use routing through internet connections, and position information and trajectory knowledge can be used to assist routing.

Broadcast protocols [17, 18] have been proposed and they use GPS information to disseminate data in a VANET. These types of protocol inform vehicles about traffic flow and congestion. The Optimized Dissemination of Alarm Messages (ODAM) protocol is used to disseminate alarm messages between vehicles about fog, obstacles, and accidents.

■ High-Accuracy Location-Aware Applications

These types of application require precise and reliable localization systems. Critical safety applications belong in this category, such as driver assistance and collision warning applications. Driver assistance applications provide comprehensive information to improve driver awareness about the surrounding environment on things like construction zones, curves, speed limits, etc. These applications reduce rear-end crashes and accidents and improve safety. They need highly accurate location information with sub-meter accuracy as to direction and approximate distance between vehicles. Collision warning applications are used for driver assistance when a vehicle in front suddenly brakes or decelerates. If the driver behind finds the distance is small and cannot stop in time, there might be a rear-end accident [19]. The application has an emergency brake feature when the distance is too short between vehicle nodes and the distance to an obstacle decreases. Another feature of this application is to inform other drivers around accident vehicles in order to avoid a pile-up by accessing multi-hop communication. These applications require an accurate localization system for safe driving. Vision enhancement applications are used to provide a clear view of vehicles and obstacles. These types of application are useful in foggy conditions and when vehicles are hidden by obstacles. The vehicles are equipped with multiple types of wireless transceivers, which make possible data communications via wireless data links. Different types of models are available for communications in transportation, such as V2V-based, infrastructure-based, V2I-based, and ad-hoc–based communications. Messaging types for transmission in transportation applications can be periodic, event-triggered, limited over a short period, and so on. The message period is related to periodic messaging applications between source and destination, and depends on the nature of the application. Critical latency is the maximum delay the application requires from the underlying protocol stack to handle and transmit the messages.

Another requirement refers to the communication range between source and destination, priority at the MAC layer, and the accuracy of the position. In Table 1, we illustrate different requirements of intelligent transportation system applications.

Localization techniques

Various localization methods have been proposed for position information and for mobile vehicle nodes. The nature of the VANET environment is very useful for most localization techniques. Figure 2 shows some localization techniques used to estimate vehicle positions, such as dead reckoning, map matching, cellular localization, image/video processing, localization services, relative distributed ad hoc localization, and cooperative localization. The localization techniques have their own characteristics and limitations. In the next section, we discuss these techniques in detail.

■ Global Positioning System/Differential Global Positioning System

A GPS is used to navigate and locate vehicles and other mobile nodes in the network. It uses a collection of 24 satellites that operate in orbit around the earth [25, 26]. Each satellite is around 20,200 km from earth and completes two orbits every day. Four satellites monitor each region of the earth. GPS receivers installed in vehicles receive information from the satellites and estimate distance using a time of arrival (ToA) technique to at least four satellites, computing position using trilateration [27].

Table 1. VANETs Applications

Application	Communication	Messaging Type	Message Period	Latency	Other Requirement	Goals
Arterial incident detection [20]	Vehicle -to-Infrastructure I2I	Event-triggered, Periodic permanent broadcast	100m	100m	Range:300m	The application is based on inductive loop detectors and probe vehicles for real-time incident detection and traffic control.
Real-time traffic speed estimation [21]	Ad hoc, V2V, V2I	Event-triggered Periodic broadcast	50m	50m	Range-100m	Through this application, the system collects probe vehicle information to estimate speed and travel time. The real-time speed estimation application uses various sensors to collect traffic information, and fusion-based estimation. The application is a more effective approach for traffic estimation and measurement, especially for urban traffic management systems. Two technologies are used in this application: Bluetooth and GPS devices. The data fusion technique improves accuracy over signal sensor approaches.
Intelligent Access Program [22]	Vehicle to Infrastructure, Vehicle-to-Vehicle	Event-triggered Permanent broadcast Periodic broadcast	100m	100m	Depends on Network	Through this system, the movement of vehicles via GPS is monitored. The system also collects vehicle location, identification, speed and time via installed sensors in the vehicles.
Forward Collision Warning System [23]	Vehicle to Infrastructure, Vehicle-to-Vehicle	Event-triggered, Broadcast	100m	100m	100m	In this proposed system, the authors use radar detection and short range communications for collision warning. The system relays distance and relative speed, and calculates braking time between host and lead vehicles via radar detection, broadcasting event-driven messages and GPS information when there is too little braking time.
Collision Warning Model [24]	Vehicle-to-Vehicle	Event-triggered, Broadcast	200m	200m	200m	In this proposed system, vehicle acceleration, speed and other information are used to avoid collisions in limited time. The system obtains these parameters using Doppler, analyzing and broadcasting the messages.

Finally, the receiver knows its latitude, longitude and altitude. Vehicles equipped with a GPS receiver are able to provide VANET localization information. Many vehicle manufacturing companies provide the equipment in their cars for localization and tracking distances, vehicle mileage, and speed, etc. The Ford Motor Company developed a telemetric system through GPS that will alert emergency services and locate the vehicle quickly for more assistance.

Figure 2. Localization techniques in VANETs

Over the years, the VANET field has become more involved in critical areas and reliant on localization systems like Galileo, GPS, GLONASS, etc. These systems have shown some undesirable issues and are not efficient for critical applications, such as collision avoidance or lane-level navigation, and some have time availability issues [28, 29]. To close the gap between availability and positioning, accuracy is required for different VANET applications. These challenges have gained the attention of researchers and industrial groups. For accurate information, the GPS receiver requirement is three satellite signals for 2D and four satellites for 3D positioning. Satellite signals are easily disturbed by many obstacles, like rocks and buildings, electronic interference, dense foliage, etc, which are a major cause of position inaccuracy. In metropolitan areas, the obstacles are tunnels, forests, underground spaces, and parking lots. The distance error in a GPS receiver is between 10m and 30m, which is reasonable for some applications but not appropriate for vehicular environments. One solution to this error is for GPS receivers close to each other to obtain a similar localization error pointing in the same direction and correlate the errors. Differential GPS (DGPS) uses this positive aspect and associated errors by installing a GPS receiver in a fixed location that is already known. Then, the GPS computes the position through received information via satellite with its already known physical position and broadcasts the differential information. Differential GPS can provide sub-meter accuracy, which is suitable for vehicular environments. Another good point about differential GPS is that correlated errors acquired through normal GPS receivers and the comparative distance between receivers can be precisely projected. One of the main disadvantages of this approach is that fixed ground-based reference stations must exist to broadcast the information. The simple GPS is used for vehicular applications and a combination of geographic information and GPS is used for high-accuracy applications in VANETs.

In the next section, we discuss localization techniques used for the source of position information to enhance and improve GPS localization and to change it in locations where a GPS is not working properly or not available.

■ Map Matching

The recent development of the geographic information system (GIS) makes it possible to store and access accurate data in the shape of city map information. Basically, a GPS trajectory contains a sequence of points with latitude, longitude and timestamp information. However, this data is not accurate because of measurement errors, sampling errors, and limitations of the GPS [30]. Map matching is a method of aligning a sequence of observed vehicle positions with the road network on a digital map. Map matching is a fundamental and pre-process step for many trajectory-based applications, such as traffic flow analysis, driving directions and object management. The data are used to provide and improve the performance of different positioning systems, like a GPS. The main goal of the system is to overcome the error of the estimated vehicle position. Map matching is a chief application used for map knowledge in localization [31, 32]. The approaches used in map matching are generally classified into three types: the local/incremental method, the global method, and the statistical method. The local method is used to find a local match of geometries, and the incremental method uses two similarity measures to estimate the candidate edges [33]. The global method is used to match the whole trajectory with the road network [34]. Statistical models are used for matching GPS observations [35]. In another study [36], Yang et al. identified the three types of map matching technologies: point-to-curve, angle of curve-to-curve, and distance of curve-to-curve. The first method matches the nearest road and GPS points; the second type matches the vehicle with the road and a smaller angle from its two GPS points. The third type matches the curve-to-curve distance of the road with the vehicle against the sum of two end GPS points. The main problem in map matching technology is that it needs extra hardware, is high in cost, and takes time to save GIS information in advance.

■ Dead Reckoning

Dead reckoning (DR) is another VANET localization technique used to compute the current position of nodes and is based on the node's last identified location with the help of movement information like distance, time, speed, direction, etc. [37]. The last known position can be acquired through GPS receivers or by locating a known reference on a digital map [16]. In other words, DR is an approach where a vehicle node estimates its current position with a bad GPS signal. VANET dead reckoning is used for a short time when a GPS is unavailable, and is combined with map information. Dead reckoning is more suitable in highway environments, compared to metropolitan areas, because the highway structure is straight and movement of vehicles can easily be predicted. Another reason is the speed of vehicles floats around an average value and is stable. In the absence of a GPS, DR is a good candidate. The many unique features of a VANET, like high speed and dynamic topology, accumulate errors easily in a dead reckoning system. That is why this system is only used for backup when a GPS is not working in tunnels, etc. The system accumulates errors easily over distance and time. For example, when a vehicle is traveling at 100 km/h, a positioning error of between 10m to 20m can occur just 30 seconds after the last position fix. One solution to overcome dead reckoning errors is merging of map knowledge and traffic patterns for matching the assessed path inside map matching [31].

■ Cellular Localization

This type of localization is based on a cellular infrastructure and is especially designed for urban areas to approximate the position of vehicles [38, 39]. The various types of application working in this type of technology include tracking animals, vehicle localization, locating mobile phones, etc. In this technology, the communications system is based on many mobile cellular systems with base stations (BSs) installed to cover the area. The BSs' responsibility is stipulating cellular communications among mobile nodes that are present within base station coverage. Whenever the mobile phones change their positions, they might also enter another base station's range, called handoff. One base station is used for communications at a time, and many base stations might listen and communicate with mobile nodes at any one time. Because of this process, various localization approaches are used to evaluate the positions of mobile nodes. Received signal strength indication (RSSI) is one of the well-known approaches for estimating distance from the base station. Furthermore, it calculates the ToA at the base station and the time difference of arrival (TDoA) for a single signal to arrive at multiple base stations. If the distance of three base stations from a mobile node is analyzed, they can calculate the position of the mobile node using multilateration and trilateration methods [40]. Another approach to localization is through antenna arrays at a base station, where angle of arrival (AoA) from three base stations can be used to analyze the position of the signal source.

Another localization approach, fingerprinting, is a pre-training phase where signal features are recorded from a base station at every location. With these records, the mobile node can find the position in a database and match the present signal characteristics. This approach is efficient for medium-sized areas because of a 2m to 5m median error achievement, and a 70m to 200m median error outdoors [41]. Cellular localization is conservatively performed with parameters like signal strength, angle, and time-release signals, but is less precise compared to GPS [42]. It also depends on the urban environment, detection of signals, base stations, positioning protocols, etc. The average localization error in cellular-based techniques is 90m to 250m [39] which is not suitable for VANET applications because a vehicular network requires accurate information. This technique is useful for position information–gathering when map matching and dead reckoning techniques are combined. The information is also used to feed data fusion modules. The one advantage of a cellular system is greater availability in urban areas, compared to GPS receivers, because the latter take signals from satellites.

■ Video- and Image-Based Localization

These video and image sources have been used for localization; some popular applications for VANETs work in parking lots and tunnels, where cameras are already installed for security. Normally, these processing approaches are based on data fusion protocols to analyze and track the vehicle node location. These video and image sources compute vehicle location parameters, such as in vision algorithms to detect the sides of lanes [43]. In this approach, estimation is possible via the vehicle's geometric parameters, like the road's lateral curvature, lane width, and distance of vehicles from lanes, angle of direction, and camera inclination angle. The data are distorted into an accurate digital map and are used for data fusion modules for vehicle node location.

■ Localization Services

GPS service is not available in some places and is not suitable for VANET applications in urban canyons, tunnels, and parking lots. To provide services, infrastructure communication is available for localization of vehicle nodes. Some popular localization systems are radar [44], ultra-wideband (UWB) [45] localization [46], WiFi localization, the Cricket location-support system [47], etc. Radar uses a radio frequency–based system to localize and track users inside buildings. The system records processing signal strength information via different base stations and combines these measurements with signal propagation modeling for location of nodes. The ultra-wideband localization scheme proposed and based on ToA uses an ultra-wideband radio link. In this system, the UWB ranging system correlates with high-speed measurement competence in every transceiver to complete two-way ranges among them without a clock. The VETRAC [48] system is based on WiFi IEEE 80211 b/g access points for location identification and tracking in VANETs. The system is used in tunnels, in airports, and on university campuses to track vehicle information via WiFi access points.

One of the main challenges in the VANET environment is development of an infrastructure localization system for tunnels, where access is limited. Rescue operations are also a difficult task inside tunnels. Dissemination of alert messages to other vehicles and rescue teams is a crucial task. In most cases, for indoor localization systems, images and cameras or laser scanners are used. Recently, VANET infrastructures have also used wireless sensor networks to monitor road variables like speed, temperature, noise, and visibility. These types of network are ideal and cost-effective, especially for emergency operations [49]. Using sensors for roadside infrastructure is an envisioned scenario for the transportation field. The sensors also improve the performance of VANET infrastructure localization systems, such as movement sensors for sending localization packets when vehicles are present.

■ Distributed Ad Hoc Localization

Another technique used in VANETs is local relative position maps to estimate the distance between vehicles and with neighbors and to exchange information. With this information, vehicles locate their own and their neighbors' positions. This type of localization is mostly used in sensor and ad hoc networks. The ODAM [3] protocol was proposed to support GPS localization in unequipped vehicle nodes. The main function of this algorithm is to estimate the vehicle position based on three nearby GPS-based vehicles. If the nearby GPS-based vehicles number fewer than three, the algorithm takes the direction and distance from an event. In this approach, the algorithm effectively approximates the vehicle position. Another approach proposed [50] a distributed VANET localization system that estimates the distance between vehicles through RSSI, and the information is used by an optimization algorithm. The proposed approach improves the GPS initial position estimation, but nearby GPS-based vehicles tend to have correlated errors, and it is hard to improve the position through RSSI. However, the proposed approach also enhances positions through dead reckoning during an outage. Some other distributed relative ad hoc and sensor networks have been proposed, and some of them are implemented in VANETs. Another approach proposed [51] relative positioning of a cluster and does not need GPS information. The proposed architecture is based on distance estimation measurements. Various types of applications are based on relative positioning, but they are not better then GPS. In some cases, the relative positions change into global positions.

■ Cooperative Positioning Localization

The cooperative positioning approach can exploit wireless communications technology for localization. Two emerging communications technologies in wireless access in vehicular environments/dedicated short-range communications (WAVE/DSRC) systems are used with the IEEE 1609 family and the IEEE802.11p standard. The two types of communications defined for this system are vehicle-to-vehicle and vehicle-to-roadside. The cooperative method presented by Wymeersch et al. [52] for wireless networks has three stages: detection or measurement, data sharing, and location update. The first stage is usually used to estimate the condition of relative objects, like distance and ID. The second stage is related to data sharing between vehicle nodes, and informs neighbors about their status, such as driving information, etc. The last stage is a location update via a data fusion method. The vehicle-to-roadside cooperative method was defined by Li et al. [53]. Another method is differential GPS, which uses ground-based reference to regulate GPS differential errors [54]. On the other hand, the vehicle-to-vehicle cooperative method overcomes the cost issue and measures relative distance via installed on-board units in vehicles, such as video and radar sensors. In the past, various authors have proposed radio-based systems like TDoA and ToA, but these systems suffer from multiple interference, noise and inadequate range [55]. Tsai et al. [56] merged dead reckoning and a cooperative positioning system to improve GPS position error in a VANET. The proposed system works without any extra prior information, such as a city map. The authors claimed that the proposed protocol reduced GPS positioning errors and showed a 15% accuracy performance in a real city environment. In another study, Ou [57] proposed a scheme where vehicles estimate their location by broadcasting beacon messages via roadside units. Figure 3 shows various localization techniques in VANETs.

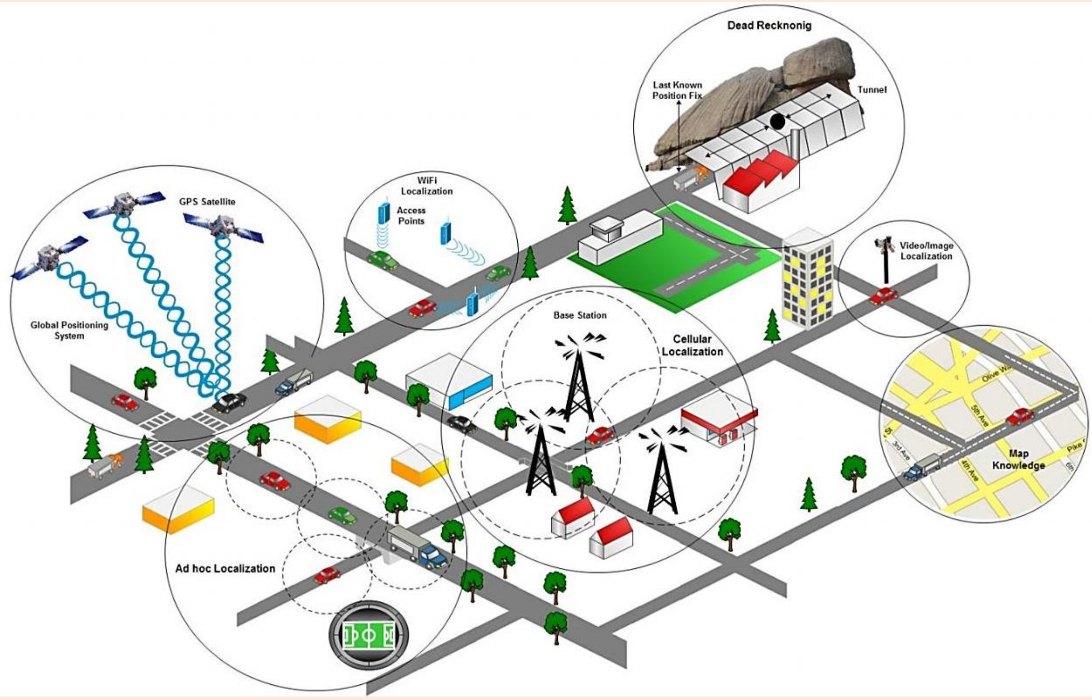

Figure 3. Localization techniques in vehicular ad hoc networks

Comparison

Various solutions have been proposed to estimate localization in VANETs. These techniques have their own limitations and boundaries, which are not suitable for VANETs' highly mobile and dynamic environments. The discussed solutions are basically not fit for vehicular critical applications and need accuracy and reliability in position estimations. Because of these weaknesses, the VANET environment needs an efficient approach, which is available anywhere, anytime. The localization systems must be free from any delay and deliver the information on time. If the information is only slightly late, it can cause dangerous accidents, etc. Only relying on satellite systems is not a good approach, because in many cases, the satellite information is not delivered properly. On the other hand, the infrastructure is also not available anywhere.

The single approach does not fulfill VANET application requirements, and there is a need for a fine-grained localization system, as shown in Table 2. There are some combined approaches for localization, such as data fusion, which we discuss in the section below.

Data Fusion in Localization system

Other terms are used for data fusion, for example, sensor fusion or information fusion. Data fusion is a technique used to improve location estimation in many sensor-based systems. It is also a combination of many sources to acquire better performance, lower costs, and obtain greater relevance [58]. Data fusion comprises algorithms, theories and tools to process many sources of information, and works well than individual sources. Data fusion is used to detect the tasks and then classify them in diverse application domains, such as military and robotics applications. Intrusion detection [59] and denial of service (DoS) [60] are two applications that have been used in data fusion mechanisms. In wireless sensor network (WSN) domains, maximum, minimum and average aggregation techniques have been used to decrease data traffic to save energy [61]. In a WSN, data fusion techniques are applied to improve localization estimation, collect link statistics, and to detect routing failure. For localization in a VANET, data fusion is used to improve location estimation in numerous sensor-based systems, such as particle filters, Kalman filters and belief theory [58].

Table 2. Comparison of Localization Techniques

Technique	Infrastructure	Availability	Accuracy	Synchronization	High Cost
Global Positioning System	✓	✗	✗	✓	✓
Differential GPS	✓	✗	✓	✓	✓
Map Matching	✗	✓	✗	✗	✗
Dead Reckoning	✗	✓	✗	✗	✗
Cellular Localization	✓	✗	✗	✓	✓
Image/Video Localization	✓	✗	✓	✗	✓
Localization Services	✓	✗	✓	✗	✓
Distributed Ad hoc Localization	✗	✓	✓	✗	✗
Cooperative Positioning Localization	✓	✓	✓	✗	✓

The Bayesian filter is a common algorithm for estimation; it calculates the probabilities of several beliefs to allow a vehicle to gather its position [62]. The algorithm provides a framework to estimate the state of the system based on probability theory. On the other hand, the Kalman filter is used as a recursive state estimator that constitutes the earliest tractable implementations of the Bayesian filter [63]. Another approach, SAFESPOT, is used for accuracy and positioning of vehicle nodes in a VANET. Data fusion combines the information from vehicle nodes to estimate location and lanes in safety applications. Data fusion combines different information sources to deliver location estimation, and is used in almost in all stages for localization systems.

■ Related Work

Fernandez-Madrigal et al. [64] proposed an approach that uses a particle filter to cope with vehicle localization for indoor or outdoor situations. For indoor situations, the authors used a UWB sensor, and for outdoors, used GPS for vehicle localization. The particle filter was used to further evaluate and observe two types of sensor. UWB is based on transmission of short pulses and uses 3.6 and 10.1GHz bands. The main features of UWB are that the signals are not affected by multiple fading and use low power and small transmitters. A GPS uses two radio channels, 1575.42MHz and 1227.60MHz, and signals are received from satellites to develop a trilateration process. Particle filters were used by Chausse et al. [43] where the authors combined a GPS with data computed by a vision system. The localization parameters are estimated through particle filters for further multimodal estimation. The authors claimed the combination of information solved the problem of unavailability of GPS data for vehicle localization. The precision is better than GPS alone (e.g., the proposed approach is 20m, whereas GPS is 48m. Michel et al. [65] proposed a multisensory-based indoor vehicle localization system for tracking position. The system uses logistics and production applications and uses Kalman filters for tracking the location of all nodes via wireless positioning system and optical scan match. The proposed system is flexible and steady for complex and dynamic environments.

In another approach, the Kalman filter and belief theory are used to make precise location estimations for vehicles available on a digital map. The approach was used to merge measurement from GPS positioning with an anti-lock braking system and to further select the most reliable roads. Selection was based on direction, speed and distance measurements using belief theory. A new opinion is then built, and the vehicle approximates the location, which is adjusted through a second Kalman filter [66]. Golestan et al. introduced a novel approach with data fusion and V2V communications to improve localization accuracy [63]. The proposed approach combines radio ranging distance measurement techniques and data fusion with V2V communications, and then evaluates the method and estimates location.

Conclusion

In this survey, localization in vehicular ad hoc networks and its challenges and techniques were studied. We showed global positioning system errors and unavailability in several situations. We discussed how these errors affect VANET safety applications. Some other solutions for localization, such as cellular, dead reckoning, video/image processing, distributed ad hoc and cooperative localization were discussed. All of these approaches have their own advantages and disadvantages. We also discussed data fusion techniques for position information. This survey will help researchers develop new efficient approaches to address localization issues in VANETs.

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