Research Article

Secure Global Positioning System For Vehicle To Vehicle (V2V) Communication

Essa Ibrahim Essa[1], Fidan T. Sedeeq[2], Mshari A. Asker[3]

[1]Network Department, Kirkuk University, Kirkuk, Iraq
[2]Electrical Engineering Department, Kirkuk University, Kirkuk, Iraq
[3]Computer Science Department, Tikrit University, Salah AL-Deen, Iraq
[1] dr.essa@uokirkuk.edu.iq

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Abstract: In this paper, we first focused on the developing a secure global positioning system for vehicle-to-vehicle (V2V) communication which adopts the secure transmission with respect to vehicle location. In literature, different existing positioning and wireless communication technologies have been presented with their detailed comparison with the global positioning system. In methodology we proposed a GPS-based model of Contention Intensity Control with Rate Control (CICRC) for efficient and secure V2V communication. We deduced the PDR and mean packet delay between heavy and low vehicle load scenarios under fully-connected vehicle network case and a hidden terminal participation case. We also presented the PDR and mean packet delay of safety messages generated with deterministic inter-arrival time and exponential inter-arrival time, respectively. Our GPS-based CICRC model provides a good match with simulation results on well-known MATLAB tool with wireless and networking toolbox. We also verified the model by showing our simulation provides good match with analytical results. Finally, comparing PDR, mean delay and PCR with proposed CICRC by some metrics, we can verify that CICRC improves V2V communication performance compared to existing communication methods. The simulation results we obtained show the packet delivery ratio under CICRC increases nearly 10% compared with that under CSMA [8] in heavy vehicle load scenarios for secure communication undermining the vehicle location. We have also found that if packet collisions occur in some vehicles at the during V2V communication, the collision probability between those vehicles in deterministic inter-arrival time will be always higher than that in exponential inter-arrival time. Average successful packet reception time under CICRC is around 20ms lower than CSMA in heavy vehicle loads, which verifies that CICRC improves on CSMA for the GPS performance especially in heavy vehicle load scenarios for secure communication.

Keywords: Global positioning system (GPS), packet delivery ration (PDR), performance analysis and simulations, V2V communication, mean delay.

1. Introduction

Every year, there are thousands of unsolved vehicle thefts and burglaries in Turkey. The Turkish police registered 44900 vehicle thefts in 2015 [1]. Moreover, only 3.5% of these crimes were solved. The number of bicycles among the stolen vehicles is 38322 and their case the success rate is even lower with 2.3% [2]. The statistics on burglary present a similar picture. The Turkish criminal figures report 42416 burglaries in 2015 and a case success rate of only 14.2% [2]. Both, the absolute numbers as well as the high percentages of unsolved cases make it apparent that there is a need for new theft protection measures. Communication between vehicles is not a new concept. Drivers have always been able to convey information to other drivers. When the automobile was first invented, drivers had the ability to yell to other drivers or bystanders, and they could also make hand signals [3]. As cars became more advanced, so has the methods of communication between them. Technologies like turn signals, brake lights, and the horn allowed for greater understanding between drivers, resulting in safer and more organized roadways. There are many uses for Vehicle-to-Vehicle communication. For example, instead of honking a horn at another car which could be misinterpreted in numerous ways, a driver could send a direct message to the other driver that clearly states his or her intentions. No other drivers would get this message, whereas all drivers in the vicinity would hear a horn and wonder if it was meant for them. Other uses of V2V communication include faster brake response. A computer would be able to react must faster than a driver if the car in front of them suddenly hits their brakes. The braking car would wirelessly signal the car behind it, so the two cars would brake almost simultaneously.

Another possible use relates to emergency vehicles. As an emergency vehicle (ambulance, firetruck, police cruiser, etc.) approaches, it could wirelessly alert the vehicles in its path, giving more time for them to get out of the way/ pull over [4]. There is another form of V2V communication called Vehicle to Infrastructure (V2I) communication. This refers to the transmission of information between vehicles and stationary roadside devices [5]. An example of this being used is a wireless toll booth. As a vehicle enters a toll road, it passes a device. The car sends its identification information to the device, including the driver’s information, and charges the driver automatically. This allows the flow of traffic to not be interrupted. Another use is automatically notifying a vehicle of the current speed limit. The roadside devices would be placed where speed limit signs today are, as well as at any intersection or place where a vehicle enters the road. The device would signal to the car, which would display the limit in a way the driver can see it. It would automatically update when the speed limit changes and can also alert the driver when the limit is about to change. Traffic light intersections could also benefit from the implementation of V2I communication, more specifically with self-driven smart cars. The lights would automatically notify the smart cars when they turn green. Additionally, vehicles can be notified about upcoming red lights much sooner.

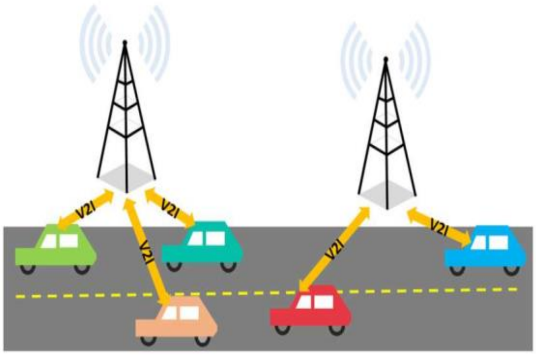


FIGURE 1. A modular diagram that depicts the vehicle to infrastructure communication [5].

The sensing encrypted range of a vehicle is defined as the range around a vehicle within which the vehicle senses the channel busy if other vehicles in the range transmit the message [6]. Vehicles sense each other message transmissions to avoid message collisions. Hidden nodes of a vehicle (node) are vehicles that do not sense each other message transmissions but they can sense the transmissions of the vehicle. Hidden nodes may lead to message collisions, as they cannot sense each other's transmissions. The hidden node problem is common in carrier sensing mechanism based wireless networks. Capture effect can reduce the hidden node problem in V2X communication.

A. PROBLEM STATEMENT

The major problems with implementing this technology include security risks, extremely limited support among vehicles on the road today, reliability, and regulation. As with all wireless communication, security is a very important topic in V2V. When V2V technology is finally implemented, data transferred between cars must be secured in real time to prevent tampering [2]. Cryptographic algorithms, encryption techniques, and GPS-based localization algorithms [3] are a few proposed solutions to this issue. We do address this problem in experiments, but it would not be difficult to add security measures to them were the measures fully planned out. The particular problem that we do address in this paper is limited support: not all cars on the road today would be able to technologically support V2V in their current states. Assuming we make it mandatory for all cars released from here on out support V2V communications, that still leaves the large majority of cars out of the picture. These vehicles would have to be included in the V2V network for the technology to work.

B. RESEARCH CONTRIBUTION

The overall goal of this paper will be to create the concept for an GPS with V2V communication as well as, the implementation of a prototype. The concept for the system is created based on a detailed analysis of the problem. This analytical model includes a stakeholder analysis and usage scenarios, as well as an analysis of existing systems. This analysis of the problem space will be used to derive a list of requirements. The solution design includes a detailed specification for the GPS components for V2V communication. Our analytic model provides a good match with simulation results. Then we studied an improvement on GPS performance. We proposed an analytical model of Contention Intensity Control with Rate Control (CICRC). We also verified the model by showing our simulation provides good match with analytical results. For completeness, the presented design is going to be very extensive. However, some of the identified requirements will be implemented completely, because their implementation would exceed the scope of this paper. The developed prototype will be evaluated to show that the implemented solution solves the previously identified challenges.

- R1: To what extent communication parameters influence vehicular communication performance?
- R2: To what extent Contention Intensity Control with Rate Control (CICRC) for V2V communication influence application performance?
- R3: To what extent does the Contention Intensity Control with Rate Control (CICRC) of GPS improve the application performance compared to existing positioning techniques reported in the literature?
- R4: To what extent coexistence of new CICRC model with the already deployed positioning affects the

application performance?
• R5: Can we experimentally validate the results of CICRC analytical model for secure vehicular communication?

2. Related work

There are many different technologies to determine an object's position, but none of them is suitable for every use case. The most widespread technology is the GPS, which newer mobile phones use. GPS determines under optimal conditions an object's location with an accuracy of several meters [7]. In urban areas and indoor settings, the precision of the positioning decreases to tens of meters. In underground locations, such as parking lots or cellars, GPS does not work at all. This section presents the most commonly used positioning system. Besides listing their advantages and drawbacks, aspects such as costs and methods used for measuring the position are elaborated. Table 1 shows a comparison of the discussed positioning techniques.

TABLE 1
AN OVERVIEW AMONG POSITIONING AND WIRELESS COMMUNICATION TECHNOLOGIES

Technology	Accuracy	Infrastructure	Cost	Domain
WiFi [7]	Meters	Medium: Several base stations must be in-stalled.	Cheap	Indoor
Bluetooth [7]	Meters	Medium: Bluetooth beacons must be distributed.	Cheap	Indoor
RFID [14]	Cell-of-Origin	High: RFID receivers must be installed and set up.	Expensive	Indoor
Cellular [9]	50 - 200 m	Low: Cellular infrastructure is already available.	Cheap	Outdoor (Indoor)
GPS	1 - 5 m	Low: GPS infrastructure is already available.	Cheap	Outdoor (Indoor)

TABLE 2
COMPARISON OF VARIOUS POSITIONING AND WIRELESS COMMUNICATION TECHNOLOGIES

Technology	Range	Transmission Rate	Expected Lifetime
WiFi [7]	<100 m	<600 Mpbs	Hours
Bluetooth [7]	<10 m	1 Mbps	1 – 2 Years
Cellular [9]	35 km	35 kbps – 10	Days

		Mbps	
LoRa [11]	2 – 15 km	0.3 – 50 kbps	Years
ZigBee [11]	10 – 100 m	20 – 250 kbps	Months to Years
GPS	3 – 50 km	10 – 1000 bps	Years

A) CELLULAR-BASED POSITIONING

Cellular-based positioning systems use the signal of mobile phone networks to determine the position of a device. There are two approaches, both assuming that the location of the cellular network antennas is known [9]. The first approach merely reports to which antenna a device is connected to, which is called a Cell-of-Origin. This method is trivial and reliable, but has a low accuracy, since these towers have a range up to 35 km [10]. The second method uses the connection to several cellular antennas and determines the device's position based on the signal strength and trilateration. However, the accuracy of this approach lies between 50 and 200 m [11]. The accuracy of both methods strongly depends on the number of reachable antennas. The coverage of this approach is close to gapless in urban areas with many cellular antennas. In rural areas with few to no antennas, the coverage, as well as the accuracy, is low. Further, the accuracy in indoor settings is worse than outdoors as the walls of the building block the antenna's signal. Connecting to a cellular requires a lot of energy, which makes this method of positioning not energy-efficient. On the plus side, costs of this methods are extremely low. Cellular receivers are cheap, and the network antennas are already deployed.

B) GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

Tuning the communication parameters may affect the application reliability and awareness range The Global Navigation Satellite System (GNSS) positioning technologies are the most prominent group of positioning systems [12]. The previously mentioned GPS belongs to this class. These systems use positioning techniques that rely on satellites, which orbit around the earth. These systems then use the satellites as reference points for triangulation. The GNSS approaches have interesting properties. Most importantly, they have a global coverage and do not rely on local infrastructure [13]. If the GNSS module has good connections to the satellites, the accuracy of these systems is in the range of several meters. However, in urban areas tall buildings often block the signal of the satellites or cause reflection. These effects decrease the accuracy of these systems. In places where the satellites are unreachable (e.g., cellars, parking lots), GNSSs are unusable. GNSSs are rather power-efficient, and the positioning takes a fraction of a second, once the chip knows the position of at least three satellites [14]. Although searching for the satellite can take up to minutes and has a high-power consumption.

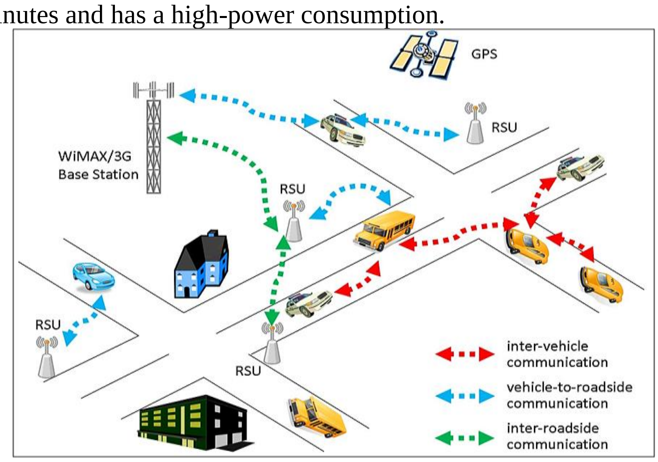


FIGURE 2. Function sequence of global navigation satellite for V2V communication through base stations [13].

C)BLUETOOTH AND WIFI

There are positioning methods which use the communication technologies Bluetooth and WiFi. These methods rely on fingerprinting, which creates an extensive list that maps positions in the area of interest to the signal strength of multiple Bluetooth beacons or WiFi base stations. The current position then is determined by looking up the current signal strengths in the list and choosing the best fit. The accuracy of these methods can be from a few to several meters [15], depending on the density of the collected data. The fundamental drawback of these methods is the need for collecting the data [16]. Also, a good coverage requires many base stations which are costly, requires a time-consuming set up, and must be maintained from regularly. The need for a dense network of base stations limits the availability of these methods significant. Regarding energy-efficiency, Bluetooth and WiFi-based approaches are interesting, because receiving signals does not require much energy [7]. Particularly interesting are approaches which use Bluetooth Low Energy (BLE), a Bluetooth version designed for low energy consumption.

D) RFID TECHNOLOGY

The very short-range RFID technology is also used for positioning. These systems rely on many receivers, installed all around the area of interest, which register the proximity of a tag and forward that to a central system. These systems have a Cell-of-Origin accuracy [17]. Due to the need for external base stations, this technology is only suited for indoor settings. It is also quite expensive due to the same reason. The big advantage of this method are the cheap RFID tags which allow tracking a large number of objects, while still being affordable. On one side, the tracked objects do not require any power source at all, as RFID tags are powered by signal, they received [17]. On the other side, the external hardware does. The fast development in the field of communications and semiconductors has led to increasing the Internet of things (IoT) applications used in all areas of life (such as industry, agriculture, transportation, health, and smart cities) [18].

3. Methodology

Though very basic and not nearly as complex as reality, our simulations still convey the usefulness of using V2V communication using Matlab with all necessary packages and toolboxes for implementation. Several factors were taken into account in our tests that would need to be addressed before actual implementation. In the case of V2V communication, message security would be the biggest concern. Communication between vehicles while driving is already a huge problem, and to avoid adding to that, this technology must be implemented differently. We proposed a new CICRC model for V2V communication through GPS Fig. 3. Perhaps it could be entirely controlled by GPS, or even completely automated by the thoughts of the driver. Receiving messages would also need to be very unobtrusive so as to minimize the distraction it causes the vehicle. The choice to receive messages would also be optional, and vehicle should have the ability to block other vehicle from communicating with them in this way.

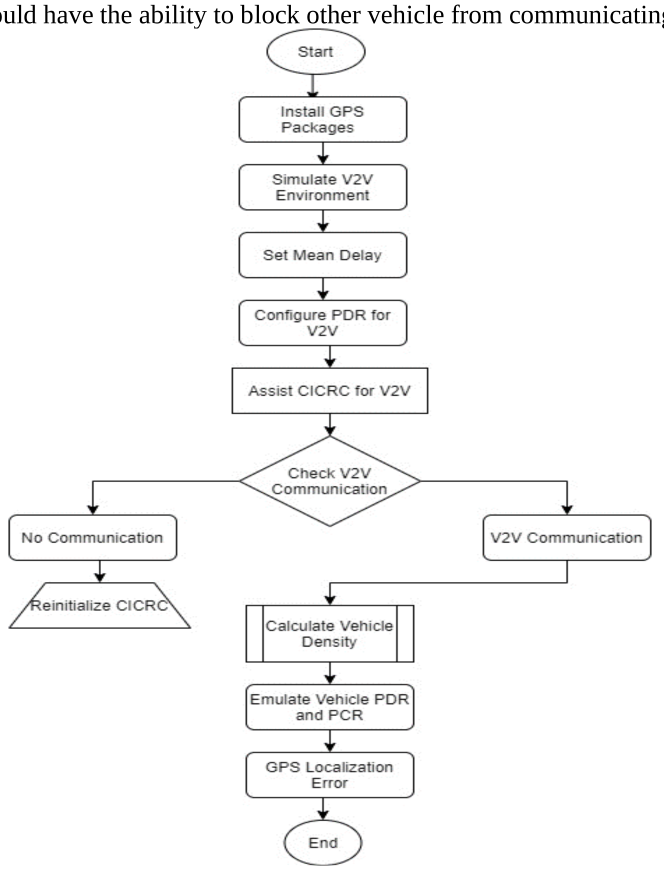


FIGURE 3. The flowchart diagram depicts the methodology.

A. *GPS* PACKET *DELIVERY RATIO*

The design and implementation of GPS Packet Delivery Ratio introduces a variety of challenges. First, the design of such a system has to be done based on an in-depth understanding of the use case to create user acceptance for the product. For instance, the physical device attached to an object has to work without failure in any environment, require little maintenance and has to be affordable as well. Also, the device must be practical, which puts some close restrictions on its size. Therefore, the selection of technology and components used has to be well planned, which necessitates a profound comparison of the available options for GPS PDR. The same holds true for the user interface on which the user controls the object tracking system. This has to be easily accessible, easy to understand but yet powerful enough to allow a fine-grained control of the object tracking. Further challenges of an PDR are privacy and security issues. They are important for MATLAB software system but become even more crucial when dealing with ubiquitous GPS devices and positional data. The difference between PDR and PCR is that people do not use them with the same level of awareness [5]. These GPS devices are integrated into a person's everyday life, so the user may forget that they are connected to the Internet. While the owner might be unaware of this, these devices still report environmental or positional data to the V2V communication. Moreover, if this data is accessed by the wrong person, this must be considered a major violation of the owner's privacy. Especially in the case of positional data which allow inference of a person's most intimate information such as religion or vehicle issues. The security issues of GPS PDR are therefore important for two reasons: Firstly, an PDR without proper security measures cannot guarantee the vehicles privacy. Secondly, an insecure PDR cannot reliably track and protect vehicle communication, because attackers can easily disable it. The PDR equation is shown below:

$$PDR = 1 - \left(1 - \frac{N^i}{V^2}\right) + (i - N) \quad (1)$$

Where *'N'* is the number of vehicle and *'i'* is the frequency of occurrence with respect to number of vehicles.

B. CONTENTION INTENSITY CONTROL WITH RATE CONTROL (CICRC)

The Contention Intensity Control with Rate Control (CICRC) for vehicular communication using GPS is very effective. We propose using it in urban areas, it has a stable connectivity – indoors as well as outdoors. In rural areas, there are regions with connectivity problems. The current cellular standard G4 is not intended for energy-constrained devices and therefore not power-efficient. A further disadvantage of the vehicular communication is that the telecommunication providers charge for its usage. The CICRC model, which belongs to the family of global positioning system, is proposed for highly resources-constrained devices for V2V communication. The small data rate of 0.3 – 50 kbps restricts its usage to use cases where little data must be transmitted. On the other hand, the technology's minimal energy consumption allows running a battery powered device up to several years. The exceptional high range of up to 15km, is a further advantage of the CICRC model. On top of the CICRC physical layer, the open source GPS stack is being developed. This standard is maintained by the CICRC model, a public consortium of various industry partners. This open standard allows developers to create private or community-driven GPS. The CICRC is such a community-driven GPS provider and has access points all over the world. It can be used for free but with limited air-time. We proposed it by using it in the wireless toolbox of Matlab for the implementation purpose based on the PDR and mean delay for the communication.

C. GPS MEAN DELAY

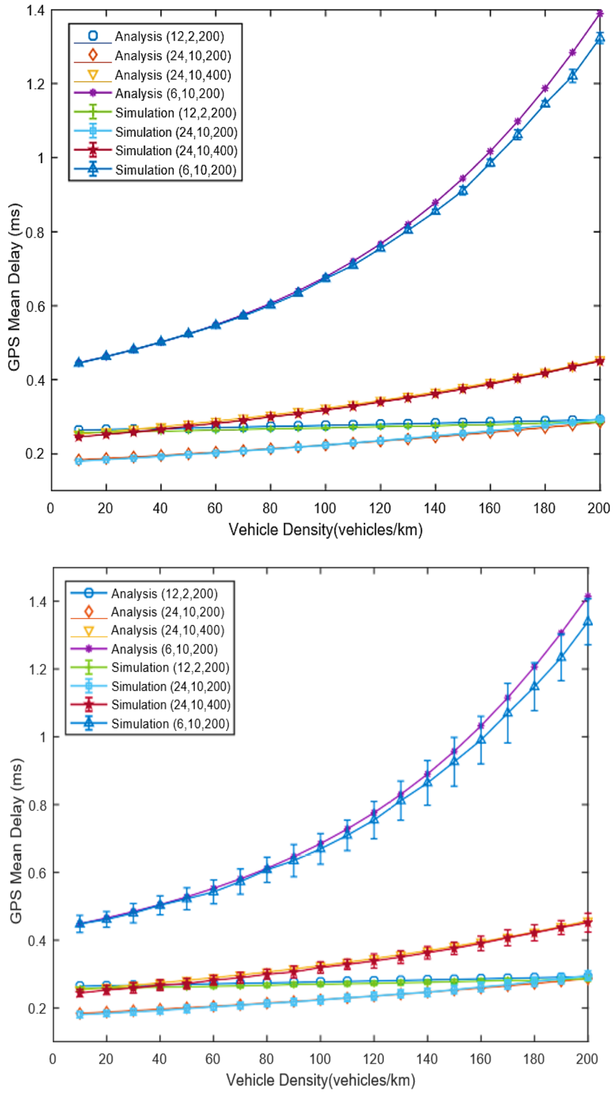
The GPS mean delay for V2V communication is a very common in communication technology. Originally developed for use cases in domestic settings, mean delay has a range of approximately 100 m. The maximum data rate depends on the version of the IEEE 802.11 standard [10]. Currently, throughputs up to 400 Mbps are possible. The IEEE 802.11 standard consumes a considerable amount of energy, as it was intended for devices that can be charged every one to two days, such as smartphones, tablet computers or laptops. The equation for mean delay is give below. When introduced, the GPS mean delay technology was intended as a replacement for the communication of remote controls. Equation (2), Mean delay is highly power efficient in operation which makes it an attractive option for communication devices. The introduction of CICRC, which further reduced the technology's power consumption, made the approach even more promising. With a short range of up to 10 m. CICRC is most suitable for domestic settings or wearables. The transmission rate of mean delay is 1 Mbps. A device with CICRC can run 1 – 2 years on a single charge for any type of communication specifically the vehicle-to-vehicle communication.

$$MD_v = \int_{-1}^{1} (N - PDR_V)^{i^2} + (i - N) \; (2)$$

4. Results

In the plotted range, the average delay increases almost linearly with the vehicle density except the case of 6 Mbps/10 packets per second/ 200 bytes. The reason why the mean delay increasing dramatically in the case of 6

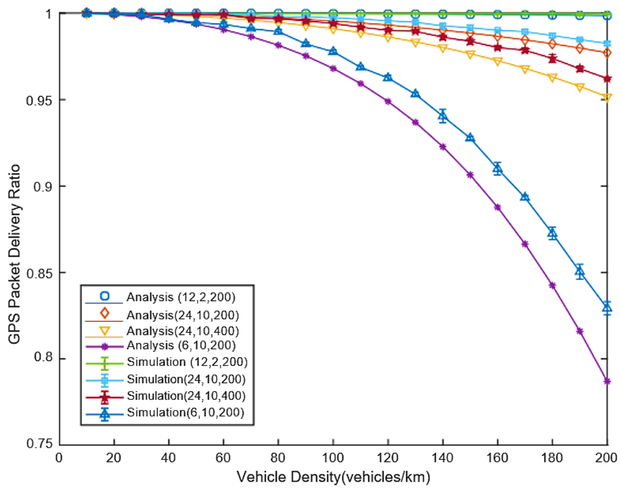
Mbps/10 packets per second/ 200 bytes can be caused by more interruptions in the back-off process in higher vehicle load and longer time of transmitting one packet.



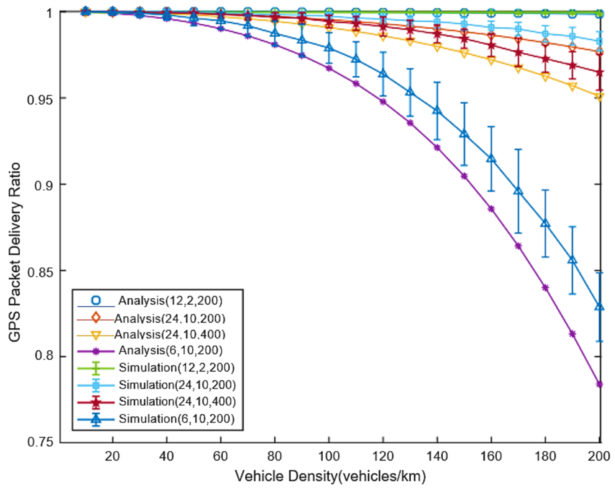
(a) Exponential inter-arrival time **(b)** Deterministic inter-arrival time

FIGURE 4. GPS Mean delay under fully connected secure vehicle communication network.

Then, we plot the GPS packet delivery ration (PDR) for fully connected vehicle network in Fig. 6. The analytical results provide a reasonable match with the simulation results. For vehicle density at 2, we can see PDR is above 99% for each vehicle density load. For vehicle density at 10, PDR drops with the increasing vehicle density load. With longer time of transmitting a packet, the PDR drops more intensely. Especially, the PDR drops to around 80% in case of 6 Mbps/10 packets per second/ 200 bytes. Besides, we can see the error bar of PDR in deterministic inter-arrival time is larger than that in exponential inter-arrival time, which can be explained by the fact that packets are generated more randomly in exponential inter-arrival time, which provides better convergence than that in deterministic inter-arrival time.



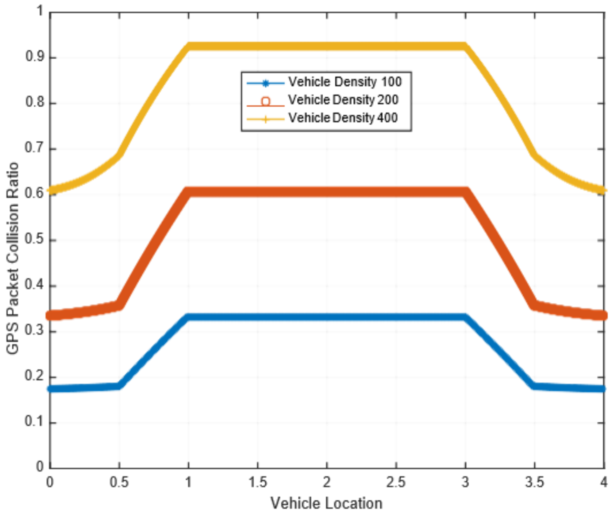
(a)Exponential inter-arrival time



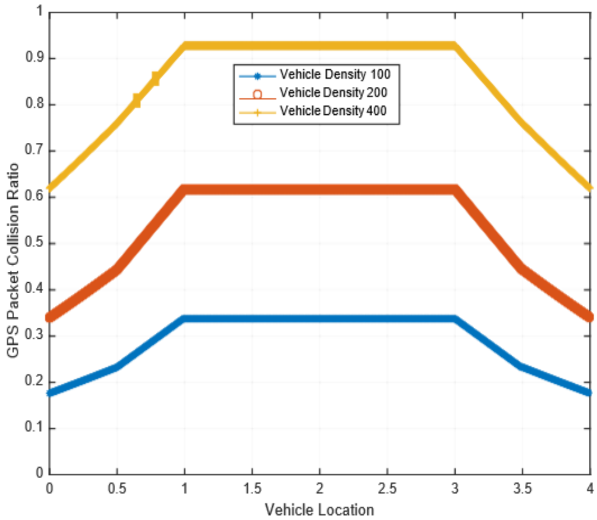
(b) Deterministic inter-arrival time

FIGURE 5. GPS PDR under fully connected secure vehicle communication network.

The mean delay and PDR with exponential inter-arrival time in heavy vehicle load for fully connected vehicle network case. We can see the difference between the analytical result and its corresponding simulation result become large in heavy vehicle density load, especially for the case of 6 Mbps/10 packets per second/ 200 bytes. We think it is mainly caused by the average collision number we proposed in the analytic model becoming inaccurate when more than two packets are involved in some collisions in heavy vehicle density load. We validate and improve the model to make it more practical. The average collision number from simulation can be tracked, we plugged it into the analytic model. We study the PDR and the mean delay in heavy vehicle density load under hidden terminal participation case. For the case of 6 Mbps/10 packets per second/200 bytes, the PDR has been below 10% with density 200 vehicles/km, which has been in heavy vehicle load. Therefore, Fig. 7 shows the vehicle location with respect to the GPS packet collision ratio (PCR) for specific range of 4km without any error in heavy vehicle load and communication.



(a) Exponential inter-arrival time



(b) Deterministic inter-arrival time

FIGURE 6. GPS Collision probability with span of 4km range with vehicle location.

We focused on the typical case (6 Mbps/10 packets per second/200 bytes) which best approximates the parameters in a real situation to compare PDR with PCR. We show the mean delay under global positioning system for vehicular communication. The mean delay under GPS is always below the mean delay under while being very close to the mean delay under 10s except in high vehicle load. For example, when vehicle load is equal to (200 vehicles/km), the mean delay under GPS radar is about 0.8ms longer than that under PDR, which can be explained by the contention intensity difference. We show the contention intensity under mean delay and contention intensity of low vehicle load and heavy vehicle load under GPS PDR. When vehicle load is equal to (200 vehicles/km), the contention intensity under GPS mean delay is two more than that under existing CSMA [8]. Due to the duration of transmitting one packet being around 0.4ms, the mean delay difference between vehicle to vehicle communication velocity will be 0.8ms. In other words, given a fixed simulation time, if packet collisions occur in some vehicles at the beginning, the collision probability between those vehicles in deterministic inter-arrival time will be always higher than that in exponential inter-arrival time.

5. Discussion

In this section we have discussed the tests performed with our application. We provide the average successful packet reception time with GPS techniques. PDR under GPS is around 20ms lower than PCR in heavy vehicle load and V2V communication, which verify that location of vehicle for communication and packet transfer takes advantage of CSMA on the GPS performance especially in heavy vehicle load for communication. Here, the average inter packet reception time includes average inter-packet generation time and mean delay. Besides, it is reasonable that the message rate decreases when the vehicle load becomes heavy because maximum message rate (10 packets/sec) is not always necessary in the heavy vehicle load scenario: Vehicles are much likely to experience a traffic jam or move slowly, a vehicle actually don't need to disseminate its GPS (updating its location, speed and etc.) with such high frequency because the variation in these parameters change little in heavy vehicle load scenario. Thus, contention intensity control with rate control makes sense in mitigating channel congestion and improving GPS performance for V2V communication.

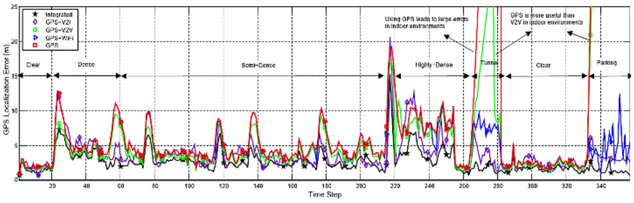


FIGURE 7. The V2V communication medium using GPS localization with respect to time steps.

6. Conclusion

In this paper, Vehicle-to-vehicle (V2V) communication is a fairly new and still developing technology that allows for wireless communication between two or more vehicles, as well as with roadside infrastructure. There unique and novel method that would be used to implement secure V2V communication for positioning known as Global Positioning System (GPS) for very first time. The is utilizing pre-existing GPS cellular networks, and the more direct method is through the use of dedicated Contention Intensity Control with Rate Control (CICRC). More than likely CICRC model will be used to fully implement the technology. V2V communication could be used to help navigation, prevent crashes, allow drivers to directly communicate with other drivers (a possible replacement for honking), and aiding law enforcement and emergency services. Problems with implementing this technology include security risks, extremely limited support among vehicles on the road today, reliability, and regulation. The emulation of numerous scenarios that show the functionality of secure V2V communication using CICRC in GPS. Our analytical model is shown to provide a good match with simulation results. We also verified the model by showing our simulation provides good match with analytical results. Finally, comparing PDR, mean delay and PCR with proposed CICRC by some metrics, we can verify that CICRC improves V2V communication performance compared to existing communication methods.

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