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The Coordinated Vehicle Recovery Mechanism in City Environments

Gwo-Jiun Horng [1]

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Abstract In this paper, an innovative, optimized and coordinated vehicle recovery network system is designed and analyzed. This system safeguards private property for all citizens, significantly enhances an existing vehicle recovery and anti-theft system, and improves the success rate for vehicle recovery. This study is not only applicable to a single vehicle but also considers the entire vehicle anti-theft communication network and connects all individual vehicles to an innovative, optimized and coordinated vehicle recovery network. Algorithms are investigated and integrated to create a highly accurate, fast, safe, and efficient innovative system that is capable of locating targets in any environment, regardless of the length of the communication distance and whether the communication comprises indoor or outdoor communication within a small area. The current study evaluates the performance of the approach by conducting computer simulations. The simulation results reveal the strengths of the proposed optimized and coordinated vehicle recovery system in terms of a reduced search time, an increased success rate of tracking and an improved success rate for vehicle recovery in VANETs.

Keywords Vehicle recovery · Anti-theft network · VANETs

1 Introduction

In countries with advanced intelligent transportation systems (ITSs), such as the United States, Canada, Japan and the European Union (EU) countries, development trends in recent years have gradually shifted from independent development toward integration. The overall development direction is to leverage an integrated vehicle infrastructure system to achieve the goals of energy saving, carbon dioxide (CO2) emissions reduction, transport system safety improvement, and traffic congestion control. Typical projects include vehicle infrastructure integration (VII) in the United States, Smartway in Japan, and cooperative vehicle infrastructure systems (CVISs) in the EU. Therefore, an investigation of the progress of VII integration system development in developed countries and the feasibility of the domestic development of VII systems is a major research topic that can provide support for transportation departments in establishing or adjusting policies and strategies for future ITS development.

ITS architecture provides a framework for the much needed overhaul of highway transportation infrastructure. The architecture's immediate effects include alleviating vehicle traffic congestion and improving operational management to promote public safety by such means as collision-avoidance improvements. Equipping vehicles with various on-board sensors and implementing vehicle-to-vehicle (V2V) communication will allow for large-scale sensing and decision-making and will help to control actions in support of these goals [1].

Countries that are involved in promoting and developing ITS are expected to leverage the momentum of ITS technology to transform transportation into a positive force that can create healthy and sustainable global economies and achieve the goals of expanding motorized power, improving transportation safety, relieving congestion, sustaining economic growth and creating sustainable environments. The deployment of ITS can achieve comprehensive and accurate vehicle recognition, real-time dynamic road condition monitoring, road control, inspection of stolen vehicles [2], and tracking of runaway vehicles in accidents. From a service perspective,

✉ Gwo-Jiun Horng
grojium@gmail.com

[1] Department of Computer Science and Information Engineering, Southern Taiwan University of Science and Technology, Tainan, Taiwan

communication devices, such as mobile phones, can be employed to publish road condition information via multiple platforms in a timely manner, guide and divert motor vehicles, and effectively relieve traffic congestion.

Many developed countries have invested a significant amount of human resources and capital to conduct tests using large-scale Internet of Vehicles technology [3]. The Institute of Electronics and Electrical Engineers (IEEE) published 802.11p as the technology for wireless access in vehicular environments (WAVE). Based on the Internet of Things, the Internet of Vehicles will become another symbol of future intelligent cities. 802.11p is a communication protocol that is extended from the IEEE 802.11 standard, which is primarily employed in dedicated short-range communication in ITS. 802.11p supports the data exchange between high-speed vehicles and between vehicles and the ITS roadside infrastructure. 802.11p has multiple enhancements for the unique vehicular environment; it also employs more advanced switchover mechanisms and mobile operations, as well as enhanced safety [4–6], identification, and point-to-point authentication.

Vehicular information and communication technology integrates communication and information. Vehicular information and communication technology has introduced functions and services, such as video and audio entertainment inside vehicles, global positioning system (GPS) positioning and navigation, sightseeing spot searching, parking lot and gas station guides, and 3G wireless communication. Next-generation vehicular information and communication systems will focus on dedicated short-range communication (DSRC) between vehicles, between vehicles and roadside units, and [7, 8] between vehicles and public infrastructure to enhance various services, such as driving safety alarms, dynamic real-time navigation, energy savings, carbon reduction and vehicle anti-theft. WAVE/DSRC is expected to become a major trend and to provide fast-moving vehicles with multi-channel operation architecture to enable vehicular and roadside devices to establish vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) short-range communication in high-speed driving environments. When this system connects to existing communication systems [2, 9, 10], such as Wi-Fi, WiMAX, and 3.5 G, features such as dynamic navigation, real-time road condition notification and driving safety alarms can be achieved.

A vehicle will become "**the 3rd intelligent space**" after the home and workspace. In the future, people, vehicles, and roads will integrate with terminal devices, service centers, service facilities and roadside devices in the environment via heterogeneous networks to form an interconnected network. Thus, scattered information can be integrated to facilitate the interaction between vehicle users, vehicles and the surrounding environment. The use of inter-vehicle communication technology will create new experiences for drivers and passengers that generate feelings of comfort, convenience, cleanness, energy efficiency, time efficiency and safety.

Vehicles are a natural theft target because they are expensive and can be easily disposed of and driven away. The first recorded vehicle theft case in history occurred in 1896, ten years after the invention of the vehicle. Vehicle theft cases have continued to increase since that time. Statistical data show that **a car is stolen** in the United States **every 20 seconds on average**.

Because vehicles have become increasingly popular worldwide, **vehicle safety management** has gained significant attention. Vehicle anti-theft systems have also gained popularity. The anti-theft systems that are currently available in the market can be divided into two categories: a Global System for Mobile Communications (GSM) notification system and a satellite positioning and tracking system. An effective vehicle recovery and protection system can locate a car in real-time, immediately notify the car owner in the event of an anomaly and obtain the vehicle's current location and condition. Because the system can locate a vehicle in real-time, it may lead to the arrest of the thief. In recent years, **vehicle anti-theft and vehicle recovery systems** have integrated GSM/General Packet Radio Service (GPRS) wireless communication with GPS satellite positioning to notify the vehicle owner. However, the scarcity of wir**eless communication base stations, attenuated signals and insufficient GPS positioning information in a small area cause notification failure and hinder locating the vehicle within a short period of time.**

This paper contributes to the research literature in four major areas: 1) using a cyber-physical alarm system to form the vehicle recovery network; 2) increasing the success rate of tracking; 3) reducing the search time for a stolen car; and 4) reducing the packet loss ratio in city environment zones to achieve these goals. In addition to system simulation and analysis, we also implement a modularized prototype of a vehicle road integration positioning system.

The rest of this paper has the following organization. Section II discusses related research on the VII problem. Section III describes the system model and the VDTNs for the vehicle recovery system in Section IV. Section V discusses the simulation. We present evaluations of experiments and implement the model in Section VI. Section VII concludes this paper and identifies future research directions.

2 Related work

This section reviews important attempts at applying VII communication in VANETs. Cloud services and intelligent vehicles method are described.

2.1 VII system

A VII system focuses on real-time communication between "people, vehicle and road" systems. To accommodate different environments, proper wireless transmission media are employed for transportation system integration. During the initial stage of ITS development, terms such as "vehicle", "road", mean ordinary car and street represent vehicles in land, water and air transport systems and their transport routes. "People" can obtain intelligence and guidance about "vehicles" and "roads" via information communication or other communication products to improve transportation safety and efficiency and achieve goals of energy saving and carbon reduction. [11] A VII system is applied research that leverages a series of advanced technologies to enable direct communication between vehicles and surrounding auxiliary facilities. The original and primary goal is to improve road safety. The basic premise of a VII system is to provide a direct link between a moving vehicle and all adjacent vehicles. These vehicles can communicate with each other, exchange information about speed, direction, driving consciousness and intension. Therefore, it can improve safety between vehicles and simultaneously improve system sensitivities of automatic emergency mechanisms (steering, decelerating, and braking). This system also facilitates communication with road infrastructure, which enables real-time traffic information of entire road networks to be complete and provide beneficial feedback.

2.2 Intelligent vehicle and cloud service

Vehicle technology can be extended from basic communication functions between two vehicles. When a user in a vehicle wants to communicate with a user in another vehicle, a high bandwidth is required for real-time video or voice transmission. When the bandwidth is sufficient and all vehicles connect to a cloud for communication, communication between two vehicles will become more diversified. In addition to providing information about approaching vehicles, vehicle technology can also be employed by a driver to communicate with other drivers and can directly replace the mobile phone because a driver can communicate with any person online.

2.3 Delay tolerant network (DTN)

In addition to the Internet, numerous communication networks, including mobile devices with limited electric power and satellites, are gradually evolving [12, 13]. Their communication technologies need to consider the unique requirement of the communication environment. These communication networks cannot use the transmission control protocol (TCP)/Internet protocol (IP) and cannot communicate with each other. They can only use a dedicated protocol for communication within their own system. Each of these communication networks constitutes a region, and every connection inside a region exhibits similar communication characteristics.

The boundary of different regions can be determined by connection delay, connection connectivity, relative data speed, error rate, addressing, reliability, and transmission quality. In contrast with the Internet, these wireless networks exhibit the following characteristics: long and varying delay, interrupted transmission, high data error rate, and significantly different relative data transmission rates. In addition to the Internet, wireless networks include interstate road networks, combat unit networks in battle fields and space networks. A proxy mechanism is required to connect networks in different regions, which can accommodate the characteristics of different networks and serve the role of buffering between two networks with significantly different transmission speeds.

In a normal arbitrary network [14–17], even if node movement will result in broken routes, most nodes are interconnected; however, due to some environmental factors and unstable topology, packet transmission usually experiences some delay. This random network is referred to as a delay network. A delay-tolerant network exhibits characteristics such as high delay, high error rate, and frequent network blackouts, which is significantly different from a conventional Internet environment. Several vehicular network architectures are proposed issues, such as DTN [18–20], vehicle delay-tolerant network (VDTN) [21, 22], cooperative DTN [23].

3 System model

In this paper, an innovative, optimized and coordinated vehicle recovery network system is designed and analyzed. This system safeguards private property for all citizens, significantly enhances an existing vehicle recovery and anti-theft system, and improves the success rate for vehicle recovery. This study is not only applicable to a single vehicle but also considers the entire vehicle anti-theft communication network and connects all individual vehicles to an innovative, optimized and coordinated vehicle recovery network. Algorithms are investigated and integrated to create a highly accurate, fast, safe, and efficient innovative system that is capable of locating targets in any environment, regardless of the length of the communication distance and whether the communication comprises indoor or outdoor communication within a small area.

In this system, a Wi-Fi base station is equipped with a hotspot network long-distance (HNLD) wireless system. When Wi-Fi base station installation becomes more popular, this system's service range will be greatly expanded. A vehicle anti-theft communication network that was previously independent can be securely integrated. We explain how to use a HNLD wireless system to send an alarm message for a stolen vehicle. A black box with a HNLD wireless system is installed in a vehicle.

We apply the concept of a HNLD wireless system and use this method to design a vehicle black box. The idea is to design a seamless network that expands from small-scale or indoor communication to large-scale or outdoor communication and is suitable for long-distance communication. This system also exhibits wireless characteristics with superior penetration and is suitable for all types of indoor communication. In addition, it is the largest wireless radio signal-based free network community and extends small-scale movable multi-angulation positioning to a large-scale vehicle recovery and anti-theft system.

Because a GPS satellite positioning system cannot receive sufficient data for an alley or indoor area, the signal strength will be significantly attenuated in an indoor environment. If the receiver sensitivity enhancement is insufficient, a solution must be obtained to address this problem. The mesh network concept and HNLD wireless system can be employed for location measurement and calculation without the need for additional hardware and network infrastructure. Measurement based on a HNLD wireless system in conjunction with satellite technology can realize fast and complete region positioning that extends beyond movable, multi-angulation positioning in a small area.

We plan to employ an algorithm as the movable multi-angulation positioning mechanism, which integrates triangulation and a gossip algorithm. It can provide effective location information in a small area for indoor or outdoor environments and perform continuous tracking. It can also immediately attain the accuracy of a small range in various environments, including urban and indoor areas. Therefore, a user can gain indoor access to a locating service with reliable operation and fast data collection. This system not only ensures the availability of fast and accurate location information but also effectively reduces the cost and power of a terminal device because an expensive network infrastructure update is prevented.

This study employs a movable multi-angulation position method to calculate the accurate location. In a conventional object positioning method, relevant data are collected for a single object to initiate the positioning calculation, that is, the object that can be located needs to continuously provide its own messages. Some messages may not be accurate, which will significantly reduce the positioning accuracy. In a typical living environment, some messages are broadcasted or the collection method may be fast and encompass a large area. The proverb "good news stays indoors while bad news has wings" can be interpreted as "the gossip message's propagation and influence are very impressive." We can employ this method as the data collection method for the positioning. Therefore, this positioning method will use the triangulation concept in conjunction with gossip data collection for positioning.

In this study, we will explain the theory that serves as the basis of the triangulation. It uses a fixed point or mobile information exchange process for positioning. Regarding the information exchange, we plan to exchange information via the gossip data collection method. When vehicles approach each other, they will exchange recently collected data, consolidate the data and make decisions. For example, if a vehicle at a crossroad receives a theft alarm message from a stolen vehicle, this message will be transmitted via a gossip transmission network. Over time, all people will receive this information and the police and the owner of the stolen vehicle will be informed to enable handling of the case.

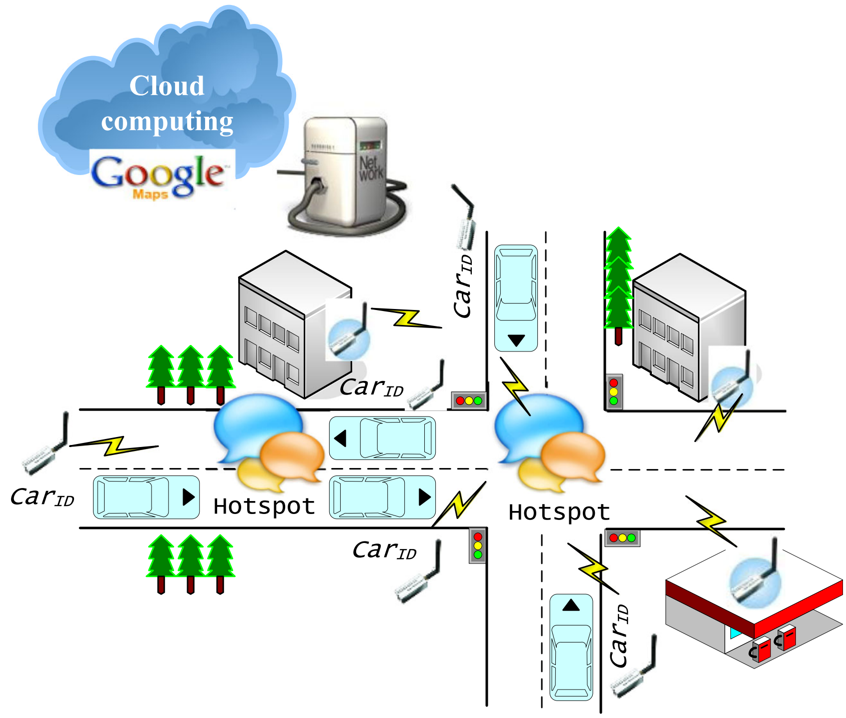
We propose an innovative design based on the concept of free and sharing. As shown in Fig. 1, a black box is installed in a vehicle as a hotspot network long-distance wireless signal transmission device. When a vehicle alarm mechanism is triggered and a vehicle is driven by an intruder, the vehicle owner will receive audio and visual notification via a handheld receiver that can successfully receive information in any environment. At this moment, the vehicle owner can press an emergency button to send a Car ID signal for vehicle locating. We must search the received information to locate the stolen vehicle or obtain information regarding its destination. The stolen car's Car ID will be simultaneously transmitted by adjacent vehicles. If this system is installed in vehicles nationwide, the vehicles can be connected to form a meshed wireless communication network. **When an optimized and coordinated vehicle recovery network system becomes more robust and has a large installation base, vehicle recovery and protection systems in Taiwan will become more comprehensive and will significantly decrease the vehicle theft rate.**

We denote each vehicle as $C_K = \{C_1, C_2, \ldots, C_k\}$, each vehicle include the license plate number. The Car_{ID} comprises the following categories of information: the driver's gender $d_i \in d_{male}, d_{female}$; vehicle number v_{ID}; and vehicle type $c_{vehicle} \in$ brand of vehicle. The Car_{ID} function is assumed to be Unicode and the corresponding signal is modeled as $Car_{ID} = v_{driver}[d_i,\ c_{vehicle}] + v_{ID}$, where $Car_{ID}(d_i)$ denotes driver's gender; $Car_{ID}(c_{vehicle})$ denotes brand of vehicle; and $Car_{ID}\ (v_{ID}[n])$ denotes vehicle ID number.

As shown in Fig. 2, cities contain many vehicles; these vehicles may be equipped with a communication device for V2V communication and hotspot communication between a vehicle and a stationary building.

When a hotspot device receives a transmitted theft alarm message, it will transmit this message to a cyber-physical alarm system (CPAS) server center. When the system receives this message, it will separate the theft alarm into two parts: the message will be calculated and analyzed via the proposed gossip mechanism and

Fig. 1 System network environment



adaptive goal programming and the vehicle position data will be processed by a maximum likelihood (ML) method to estimate the most likely location and the location data will be constantly updated. In addition, the generated data will be sent to a police vehicle and the owner of the stolen vehicle.

When the vehicle alarm mechanism is triggered and the vehicle is driven by an intruder, the searcher of the stolen vehicle (alarm message receiver) will locate the vehicle based on the theft alarm message. At this moment, the owner of the stolen vehicle search for the vehicle using the alarm message receiver and numerous vehicles equipped with these devices also receive theft alarm messages. Thus, the vehicle owner will receive audio and visual notification via a handheld receiver and successfully receives information in any environment.

As shown in Fig. 3, the stolen vehicle will automatically send the stolen vehicle's Car ID, location and direction to adjacent vehicles and stationary hotspot devices. The message received by mobile devices will be sent to nearby stationary hotspot devices. When a hotspot device receives a message (Car_{stolen}, location, and direction), it will send the message to the CPAS, which will calculate and update Car_{stolen} (location and direction). The calculated data will be transmitted to a police vehicle via stationary hotspot devices, and a message will be constantly updated to intercept the stolen vehicle.

We present a connected network of n cars with a connectivity graph G = (V,E). This network graph G changes over time in terms of V and E. Each car, $i \in$ V, has its own information denoted by x_i. The information x_i can be thought of as a collection of bits, a packet or even a real number. The interest is in spreading or disseminating this information to possibly different subsets of nodes in V. The car wishes to compute a function $f_i(x_i,\ldots,x_n)$ using a gossip mechanism. Under a gossip mechanism, the operation of any car, must satisfy the following properties: 1) The mechanism should only utilize information

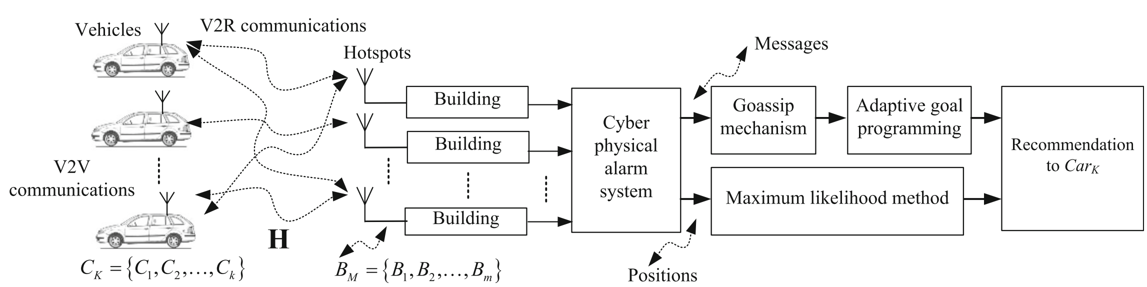


Fig. 2 coordinated vehicle recovery network system model

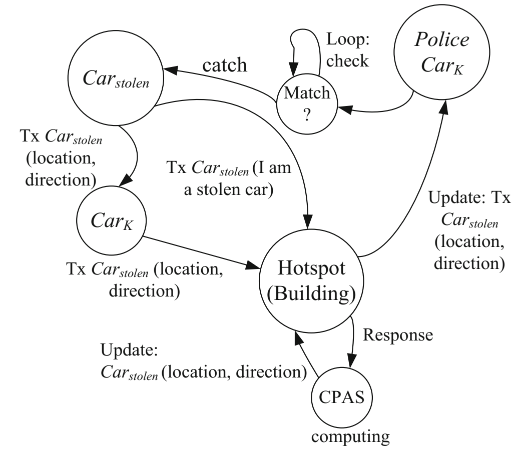


Fig. 3 Diagram of the state transition system

obtained from its neighbors; 2) The mechanism does not require synchronization between car i and its neighbors.

Because information is propagated, some information will not be transmitted to locations near the stolen vehicle. A vehicular system is a mobile system; thus, an adaptive and goal-optimized decision rule should be employed to calculate and analyze the closest and most reliable information and to notify the driver and police. This study uses **Adaptive Goal Programming to** solve an optimization problem. Goal programming is a type of linear programming that was proposed in 1961 by Charnes et al. Goal programming can solve a goal optimization problem and problems with conflicting goals. Goal programming can consider user strategy and known information, decide priority based on **each goal's relative importance**, or assign different weights within the same priority to help evaluate the likelihood to achieve predefined goals. It can also generate concrete numbers to facilitate subsequent comparison, selection and analysis. Conventional linear programming only seeks the maximum or minimum value of the objective function under constraint. When the maximization or minimization condition is satisfied, the optimization goal is achieved. Goal programming focuses on the outcome of the system operation or resource utilization, plans the outcome of an individual target for given conditions, and determines the minimum gap between the goal and the outcome.

We use priority-based goal programming in system design. Goal importance has different priority levels, and each goal has a different level of importance, that is, the priority of each goal is in hierarchical order. Thus, goals are sorted according to priority and then solved in this order. The solution for a goal with higher priority is used as the constraint for a goal with lower priority. For instance, when the first priority goal has been solved, the obtained solution is employed as the constraint for the second priority goal; then the second goal is solved. In parallel goal programming, no priority difference is observed between goals and the goal item with greater importance will be assigned a higher weight. The general formula is as follows:

$$Minz = \sum_{k=1}^{K} w_k^- d_k^- + \sum_{k=1}^{K} w_k^+ d_k^+ \quad (1)$$
$s.t.$

Goal constraint	$\sum_{j=1}^{n} c_{kj} x_j + d_k^- - d_k^+ = g_i, \forall k$
In the formula,	$\sum_{j=1}^{n} c_{kj} x_j$ represents the attribute
	$d_k^- - d_k^+$ represents the deviational variable
	g_i represents the target
Function constraint	$\sum_{j=1}^{n} a_{ij} x_j \leq (=, \geq) b_i, \forall i$
Non-negative constraint	$n_i, p_i \geq 0 \;, \forall i \;\; x_j \geq 0 \;, \forall j$
Complementary relation	$n_i \times p_i = 0 \;, \forall i$

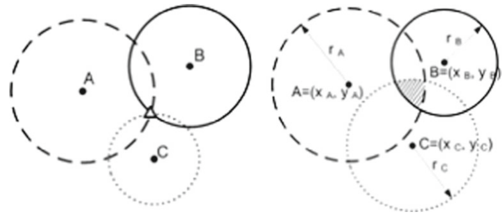
The design in this study uses priority-based goal programming, in which the goal priority is assigned by the decision maker. Goals at each stage are optimized. The optimum solution for goals with higher priority will not be affected and compromised by goals with lower priority. Therefore, this system's objective formula is as follows:

$$\begin{aligned} & Min\ Z = \{n_i, p_i\} \\ & s.t. \\ & \sum_{j=1}^{n} (a_{ij} x_j) + n_i - p_i = b_i \;\; \forall\ i = 1, 2, \cdots, m \;\; j = 1, 2, \cdots, n \\ & n_i \times p_i = 0 \;, \; \forall\ i = 1, 2, \cdots, m \\ & n_i,\ p_i \geq 0 \;, \; \forall\ i = 1, 2, \cdots, m \\ & x_j \geq 0, \; \forall\ j = 1, 2, \cdots, n \end{aligned} \quad (2)$$

In the formula, *xj:* each model's decision variable; b_i: each model's objective; a_{ij} regression coefficient; n_i: negative deviational variable when the *(i)th* objective is underachieved; p_i: positive deviational variable when the *(i)th* objective is exceeded; $ni \times pi = 0$: positive and negative deviations cannot co-exist

Triangulation is the most commonly used algorithm in the positioning system; its principle is to use three anchor points with known location information to determine the location of a test point. If the distances from the test point to the anchor points and the coordinates of the anchor points are known, the test point's coordinates can be calculated. The target that needs to be located employs distance measurement technology (e.g., radio signal strength, RSS) to estimate the distance from itself to each reference point. If the distances to three or more reference points are known, the location can be estimated, as shown in Fig. 4a. For instance, a GPS employs this method for positioning.

Figure 4a shows the case of an ideal situation; an actual situation will be more complex. In most circumstances, three



(a) (b)

Fig. 4 (**a**) Schematic diagram of trangulation; (**b**) Schematic diagram of trangulation deviation

circles will not intersect at a single point; thus, the condition of three concurrent circles cannot be used to determine the final positioning point, as shown in Fig. 4b. Therefore, the maximum likelihood method is typically used to estimate a target object's location. r_A, r_B, and r_C .represent the distances estimated from the reference points A, B, C, respectively, and the minimum σ_{xy} is used to determine the target object's location.

$$\sigma_{x,y} = \left|\sqrt{(x-x_A)^2 + (y-y_A)^2} - r_A\right| + \left|\sqrt{(x-x_B)^2 + (y-y_B)^2} - r_B\right| + \left|\sqrt{(x-x_C)^2 + (y-y_C)^2} - r_C\right| \quad (3)$$

If an object that needs to be located is continuously moving, then three or more fixed reference points must be constantly identified to estimate the object's location. This process will significantly affect positioning accuracy and speed. In this paper, each fixed point is assumed to be equipped with a hotspot network long-distance wireless referral work station and every mobile point (e.g., vehicle and people) will be equipped with a hotspot network long-distance wireless signal device. Vehicles will exchange data with hotspot network long-distance wireless signal base stations in buildings and adjacent vehicles.

In addition to the use of three fixed points (hotspot network long-distance wireless signal base station in buildings) as reference, information from mobile points (vehicle or people equipped with hotspot network long distance wireless signal device) can also be used as a reference. Using this concept, we use the principle of triangulation and significantly increase the number of reference points to obtain more abundant information for reference, which improves the positioning accuracy and speed.

Suppose there is a sample $x_1, x_2, \ldots, x_n$ of n independent and identically distributed observations coming from a distribution with an unknown probability density function $f_0(\bullet)$. It is, however, surmised that the function f_0 belongs to a certain family of distributions $\{f_0(\bullet|\theta), \theta \in \Theta\}$, where θ is a vector of parameters, called the parametric model, so that $f_0 = f(\bullet|\theta)$. The value θ_0 is unknown and is referred to as the *true value* of the parameter vector. It is desirable to find an estimator θ that is as close to the true value θ_0 as possible. Either or both of the observed variables x_i and the parameter θ can be vectors.

To use the method of maximum likelihood, one first specifies the joint density function for all observations. For an independent and identically distributed sample, this joint density function is

$$f(x_1, x_2, \ldots, x_n|\theta) = f(x_1|\theta) \times f(x_2|\theta) \times \ldots f(x_n|\theta) \quad (4)$$

The maximum likelihood estimator coincides with the most probable Bayesian estimator given a uniform prior distribution of the parameters. The maximum a posteriori estimate is the parameter θ that maximizes the probability of θ given the data, given by Bayes' theorem as:

$$P(\theta|x_1, x_2, \ldots, x_n) = \frac{f(x_1, x_2, \ldots, x_n|\theta)P(\theta)}{P(x_1, x_2, \ldots, x_n)} \quad (5)$$

where $P(\theta)$ is the prior distribution for the parameter θ, and $P(x_1, x_2, \ldots, x_n)$ is the probability of the data averaged over all parameters.

Because the denominator is independent of θ, the Bayesian estimator is obtained by maximizing $P(x_1, x_2, \ldots, x_n \mid \theta)P(\theta)$ with respect to θ. If we further assume that the prior $P(\theta)$ is a uniform distribution, the Bayesian estimator is obtained by maximizing the likelihood function $f(x_1, x_2, \ldots, x_n \mid \theta)P(\theta)$. Thus, the Bayesian estimator coincides with the maximum-likelihood estimator for a uniform prior distribution $P(\theta)$.

For the normal distribution $N(\mu, \sigma^2)$, which has probability density function

$$f\left(x\middle|u, \sigma^2\right) = \frac{1}{\sqrt{2\pi}\sigma} e^{\left(-\frac{(x-u)^2}{2\sigma^2}\right)} \quad (6)$$

$$\hat{u} = \overline{x} = \sum_{i=1}^{n} x_i / n$$

where $\overline{x}$ is the sample mean.

Based on the definitions, the likelihood function and the maximum likelihood estimator of μ, the mean weight of all locations, can be identified. Using the given sample, the maximum likelihood estimate of μ can also be determined. Next, we investigate how to improve the vehicle recovery efficiency using the relevant network transmission method.

4 VDTNs for vehicle recovery system

We know that hotspot network long-distance wireless signal coverage will affect a vehicle recovery system's success rate. An optimized and coordinated vehicle recovery network system's hotspot network long-distance wireless signal systems are fixed manual installations. However, signal coverage is highly dependent on the installation location. Due to constraints such as installation permission, cost and landform, a server may not be installed in the originally planned area, which will produce incomplete signal coverage.

When a stolen vehicle travels out of an area that is covered by a hotspot network long-distance wireless server signal, the broadcasted alarm information cannot be received and transmitted. To address the problem of low vehicle recovery success rate, we use a VDTNs communication protocol, which is a very popular technology in the area of ultra-long distance network transport, as the solution.

Therefore, the characteristics of a VDTN are employed, and ordinary passing by vehicles will function as cruisers that collect the stolen vehicle's wireless signal and Car ID. When a cruiser has a GPS self-positioning signal, two vehicles can exchange information with each other. At this moment, the cruiser will search the access point that can report to the server and send this discovered signal to the vehicle owner or police station.

A VDTN is a network environment that is insensitive to time delay, environments of mobile devices with limited electric power, satellite communication, and incomplete network coverage. These networks have the following characteristics: long and varying delay, transmission interrupt, high data error rate, and significantly different relative data transmission rates, which are situations addressed by a DTN.

In a conventional arbitrary wireless network, the routing protocol assumes that the entire network is connected. Even if node mobility will create or terminate some connections, most nodes are connected. Network connection is intermittent; the connection between nodes will change over time; and new connections will be created or existing connections will be terminated. In these situations, a node typically has a queue for temporary packet storage; when a new connection emerges, it can continue packet transmission. When a network connection is unstable, each packet transmission will experience a long delay; this vehicular arbitrary wireless network can be referred to as a VDTN.

To improve the performance of a VDTN and improve the routing success rate, a buffer is added to a node to temporarily store unsent packets; when a connection condition improves in the future, transmission can be continued. The main goal of a VDTN is to provide a comprehensive bi-directional communication method in heterogeneous networks and to provide an acceptable network performance in the environment of packet loss, excessive delay, error, and temporary connection disruption.

Next, we describe a vehicle recovery system's VDTN and a hotspot network device's long-distance wireless signal. Signal connection disruption is caused by the relatively long distance between a hotspot network server and a stolen vehicle. Thus, we implement the delayed packet transmission in a vehicle with a hotspot network transmitter and convert it to a transmission relay station between a stolen vehicle and a hotspot network server. Any vehicle can receive a message from a stolen vehicle's hotspot network device and transfer it to a hotspot network server. Its operational mode and function are as follows:

When the theft condition is satisfied, a vehicle periodically sends a stolen vehicle message (SVM) via a hotspot network device, as shown in Fig. 5-(1). The stolen vehicle will be suspended, which will send a Beacon packet to announce information, such as subsequent encapsulation action and operation schedule, hibernate duration. Then, it will send an SVM, receive server ACK information (SA) from the hotspot network device, trigger sensing and scaring (SS) action in the stolen vehicle, and remain in a hibernation state to save electric power (Inactive). Because a stolen vehicle is in a stationary state, a thief has limited options or may already have escaped from the vehicle. Therefore, actions do not need to be executed in every cycle. If the stolen vehicle is moving, the thief should be inside the vehicle; therefore, SS actions should be continuously executed and monitored in the stolen vehicle, as shown in Fig. 5-(2).

When the stolen vehicle does not receive an ACK response, the vehicle is not in the hotspot network long-distance wireless signal server's communication range and the stolen vehicle's transmission strategy will switch to DTN mode. As shown in Fig. 5-(3), (4), a stolen vehicle will specify DTN mode in the Beacon packet, vehicles that pass and receive this Beacon packet will pass the ACK message to the stolen vehicle and transmit the stolen message to the hotspot network long-distance wireless signal server. The difference between diagrams 5-(3) and 5-(4) is that the stolen vehicle is in a different state: stationary versus moving.

However, if an ordinary vehicle needs to receive an SVM, the SVM transmission period (SV period) should not be excessive. Whether an ordinary vehicle can receive a Beacon packet when it travels through a hotspot network long-distance wireless transmission area should be considered. Therefore, the message transmission period and duration should be determined by factors such as its driving speed, ordinary vehicle's estimated speed, and hotspot network long-distance wireless transmission range, which are included in the following formulas:

$$\text{SV Period} = \frac{T_r}{V_{nv} + V_{SV}} \tag{7}$$

where T_r is the hotspot network long-distance wireless transmission range (diameter); V_{nv} is the upper limit for the vehicle speed on a common road; and V_{sv} is the speed of the stolen vehicle. We assume that an ordinary vehicle's driving direction is in the opposite lane, and deduce that the maximum relative speed of an ordinary vehicle versus stolen vehicle is $|V_{nv}+V_{sv}|$. The calculated SV Period is used as the message transmission period.

Fig. 5 Vehicle periodically sends SVM via a hotspot network long-distance wireless signal

When an ordinary vehicle receives the DTN mode stolen message outside of the signal range of the hotspot network long-distance wireless server, it saves this information packet in a buffer and continues to detect other SVMs or hotspot network long-distance wireless servers. When this vehicle approaches the first hotspot network long-distance wireless server, it sends an SVM to the server to complete its mission as a DTN transmission relay station.

This model assumes that each driver in the following vehicle maintains a safe distance from the leading vehicle and the deceleration factor is taken into account for the braking performance and drivers' behavior. The complete mathematical model is given by

$$S' = L + \beta' V + \gamma V^2 \quad (8)$$

where *S*' is the headway spacing from the rear bumper to rear bumper, *L* is the effective vehicle length in meters, and *V* is the vehicle speed in meters/second. β' is the driver reaction time in seconds, and the γ coefficient is the reciprocal of twice the maximum average deceleration of the following vehicle.

The car-following model is extended to the road level by replacing the lane-level reaction time β' with a road-level inter-arrival time β. The lane-level car-following model can be generalized as

$$S' = L_{min} + \beta V \quad (9)$$

where L_{min} is the minimum spacing between any two adjacent vehicles, which is assumed to be zero in this study.

This system uses a Fon commercial network system as a reference and installs a hotspot network long-distance wireless signal transceiver in the Wi-Fi base station. The user can activate this system's free notification function by sharing Wi-Fi. When the Wi-Fi base station installation becomes more popular, the system's service range will be significantly extended. The previously disconnected vehicle anti-theft communication network can be securely integrated. This system uses light radio Wi-Fi. The solution incorporates wireless and IP technology. High-capacity and safe Wi-Fi seamlessly connects vehicle terminal devices. Light radio multi-standard Femtocell and Metrocell systems incorporate a Wi-Fi option. Among them, Metrocell provides high network capacity and wide network coverage in densely populated areas such as downtown areas and airports. Femtocell is employed as a personal base station to expand residential areas and to enable users to automatically switchover between mobile network, home Wi-Fi or public Wi-Fi hotspots. Femtocell requires neither a separate login nor extra charge, and the switchover speed is extremely fast. This technology will implement the previously mentioned function via three methods: it uses software to help users automatically identify, switchover, and connect in areas covered by trusted Wi-Fi networks and to improve network capacity.

5 Simulation and discussion

In this section, we present the simulation and discussion of a vehicle-infrastructure integration using the CPAS mechanism under an urban environment. Table 1 shows the simulation parameters and the range of values. The chosen parameters should resemble those of high network density urban areas.

In the current study, we assume that in a real-world vehicle network environment, a vehicle's speed is affected by the Doppler effect and by any data communication's success rate on the spectrum sensing problem. After we simulated and analyzed the different numbers of vehicles and the different vehicle speeds through MATLAB, we considered many factors, including the simulation area, number of vehicles, number of lanes, number of intersections, distance between intersections, RSUs, and adjustable vehicle speed. This paper evaluates the performance of the proposed scheme. This work randomly distributes 250 to 1800 vehicles in a 5.0 x 5.0 km^2 field.

Figure 6 shows an analysis of the time required to track a stolen vehicle and the number of vehicles in the city. Three mechanisms are investigated and compared, including the random work mechanism, the mobile mechanism and the proposed CPAS mechanism. The random work mechanism describes the time required for alarm processing when vehicle theft occurs in normal conditions. The police station will

Table 1 Simulation parameters

Factor	Range of values
Simulation area	5.0×5.0 km^2
Number of vehicles	250-1800
Number of lanes	2 per direction
Distance between intersections	350 m
Distance between RSUs	500 m
Vehicle speed	10 – 70 km/h

notify the police in the region to patrol and track within a region. Although other nearby vehicles may occasionally discover and send notifications, the number of nearby vehicles will affect the time required to discover the stolen vehicle. Because the stolen vehicle is moving at high speed, it requires a large amount of time to search and track the stolen vehicle and arrest the thief.

Then, the mobile mode is analyzed and compared. In mobile mode, an ordinary vehicle is equipped with a high-tech positioning module. When a vehicle is stolen, it will periodically send vehicle positioning information and vehicle positioning information via a message to the vehicle owner and relevant vehicle security guard. Due to a vehicle's highly mobile nature, which belongs to the large-area positioning mode and different landforms, positioning information signal may be attenuated or become completely lost despite the availability of vehicle positioning information. Although the coordinated search time is shorter than the duration in conventional mode, it requires a significant amount of time.

As shown in Fig. 6, when the number of neighboring vehicles increases in the case of the random work and mobile mechanism, an increase in adjacent vehicles around the city may increase the likelihood of a stolen vehicle case report, which facilitates the analysis in areas with concentrated

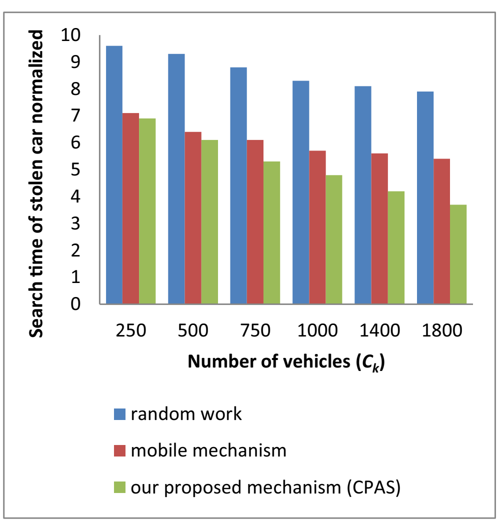


Fig. 6 Search time of stolen car for number of cars

message propagation. Thus, police in this area may require less time to track a stolen vehicle and arrest the thief. However, the proposed CPAS mechanism can take advantage of the increased number of vehicles. The gossip protocol in conjunction with the adaptive goal programming's selection mechanism can yield the desired results and quickly search and retrieve a stolen vehicle.

Next, the number of vehicles that have received stolen vehicle message notifications is compared and wait periods prior to the arrest of a vehicle thief are analyzed. Figure 7a shows the average wait period prior to arrest for three mechanisms, including the random work mechanism, mobile mechanism and proposed CPAS mechanism. The proposed CPAS mechanism employs gossip protocol to collect messages from adjacent vehicles and incorporates the adaptive goal programming's selection mechanism. Thus, the proposed method requires less time to complete the arrest. Although the remaining two mechanisms have a multi-point case reporting method as well as information and case location analysis, they cannot narrow information and do not have an accurate positioning method and highly efficient DTN communication protocol.

Due to diversified road conditions in an urban environment, such as buildings, corners, and crossroads, search and tracking can be time-consuming if police vehicles are the only employed vehicle. Next, we investigate coordinated information transmission using police vehicles, adjacent vehicles and stationary buildings to achieve a higher tracking success rate. As shown in Fig. 7b, the analysis and comparison of different mechanisms indicates a tracking success rate that surpasses other cases when vehicle and hotspot percentages are each 50 %.

The proposed CPAS mechanism for this system is investigated. A DTN-only configuration is compared with a gossip-only configuration and the packet loss ratio is analyzed, as shown in Fig. 7c. Various communication transmission distances are addressed; when the communication area expands, the DTN protocol can compensate the flaws of wireless transmission in a large area. Therefore, the proposed CPAS mechanism can achieve a low packet loss ratio in various environments, including large or small areas: in small areas, gossip can be employed; in large areas, a DTN can be employed.

The information propagation success rate is analyzed. Figure 7d shows and compares four different conditions, including integrated gossip and DTN for vehicles at speeds of approximately 50 or 80 mph, and two other cases with only the DTN or gossip mechanism. Various communication distances are used to analyze the information propagation success rate. For short communication distances, the success rates of four different conditions exhibit a relatively high level, with an increase in communication distance, and the success rates for different conditions begin to significantly vary. We also discover that the Doppler effect is insignificant in urban areas when vehicle speeds are less than 90 mph.

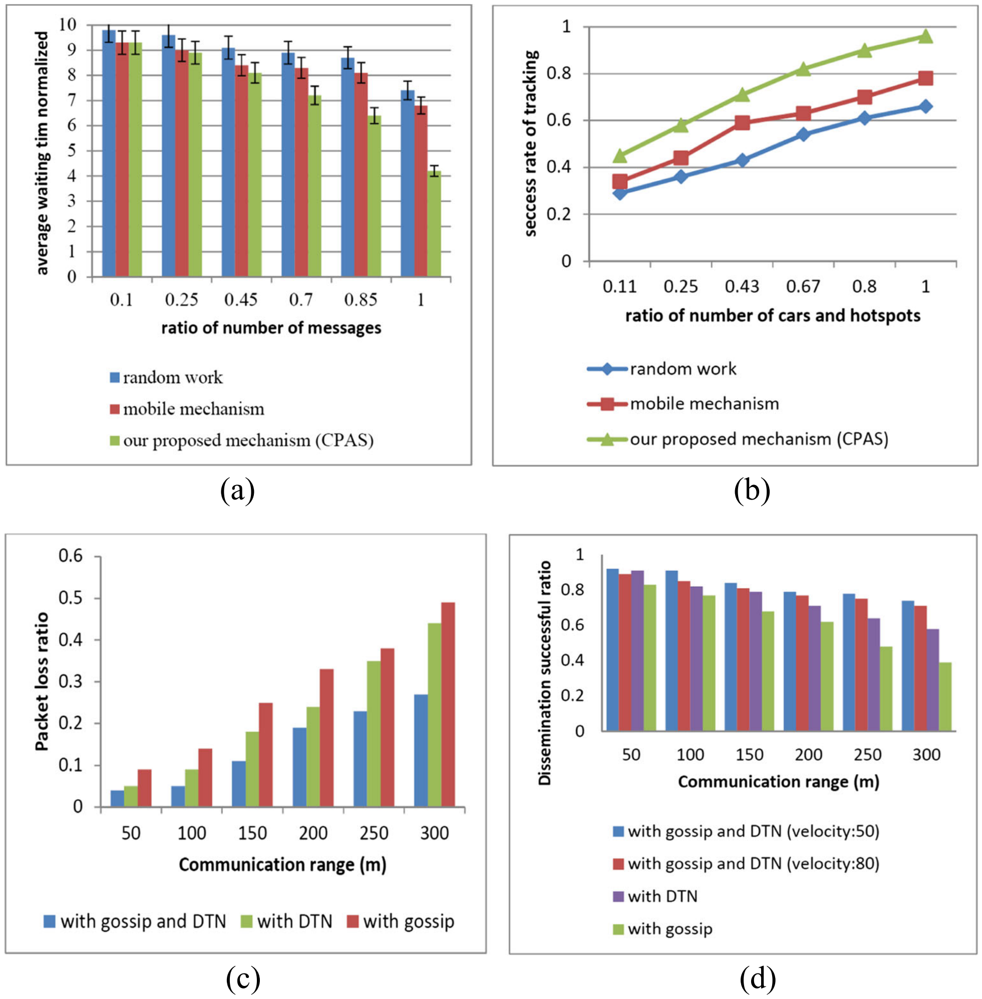


Fig. 7 (**a**) Average waiting time for ratio of number of messages; (**b**) Success rate of tracking for number of cars and hotspots; (**c**) Packet loss ratio for communication range; (**d**) Dissemination successful for communication range

6 System evaluation

In addition to system simulation and analysis, we also implement a modularized prototype of a vehicle road integration positioning system. Figure 8a shows the transmission of information from hotspots installed in stationary urban buildings to a CPAS server for additional calculations. Figure 8b shows that a hotspot is installed in vehicle to facilitate V2V and vehicle-to-infrastructure wireless information transmission. During software development, open system and architecture and the OpenWRT design model are combined. Different mechanisms and applications are compared, and the mobile mechanism is also simulated and analyzed. The modularized prototype is implemented and a comparative analysis is performed, as shown in Fig. 8c.

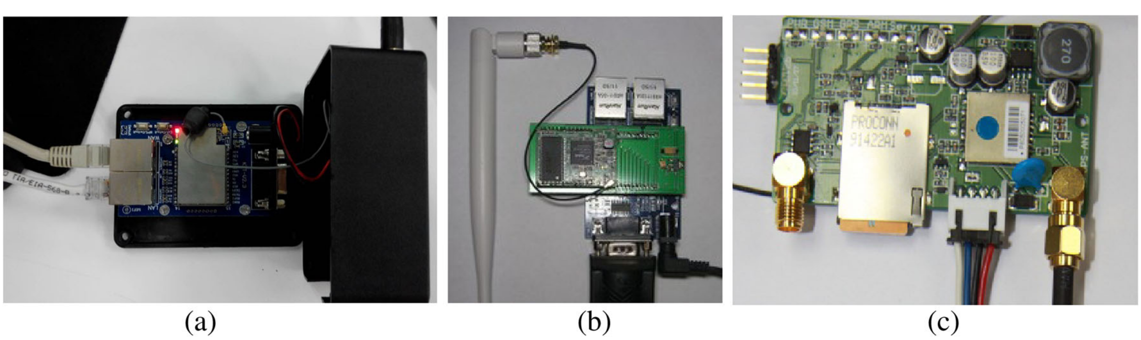


Fig. 8 (**a**) Hotspots installed in stationary urban buildings; (**b**) shows that a hotspot is installed in vehicle to facilitate V2V and V2I; (**c**) Mobile mechanism (GPS and SMS)

7 Conclusion

In the paper, we propose an innovative design that optimizes a collaborative vehicle-finding network system, the design of vehicular cyber-physical alarm system and an information fusion platform with the purpose of protecting citizens' private property, enhancing anti-theft systems and increasing the chances of finding cars in a smart city to make vehicles safer, more convenient and suitable for sustainable development in urban areas. We design a cutting-edge algorithm that provides an accurate, fast and safe system for any environment, communication distance, indoors and even outdoors. We conclude that our proposed protocol achieves substantial improvement of the success rate for vehicle recovery, increases the success rate of tracking, and reduces the search time in VANET environments. In the simulation, our mechanism was better than others. We conclude that our proposed protocol achieves substantial increases in the success rate of tracking, reduces the packet loss ratio, and reduces the search time for stolen cars in cyber-physical alarm city environments.

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