國立交通大學

資訊學院資訊科技（IT）產業研發碩士專班

碩士論文

道路監控:基於車間通訊之可疑車輛追蹤與回報系統

Surveillance On-the-Road: A Suspicious Vehicle Tracking and Reporting System Based on V2V Communications

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中華民國九十九年六月

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摘　　要

由於車載無線存取能力/特定短距通訊 (WAVE/DSRC) 和嵌入式監控系統科技迅速的發展，已使得車輛監控網路成爲可能。車輛監控網路科技將在車輛上，配備影像攝影機，並用來監控位於道路上的各種事件。在這篇論文中，每台車輛將配備有影像攝影機，並結合車牌辨識 (LPR) 技術，來做到識別可疑車輛(如:贓車)之目的。此外，亦利用WAVE/DSRC爲車載無線通訊介面，透過車間通訊 (V2V) 的技術，完成協同式可疑車輛的追蹤和快速回報此發現訊息於道路上最近的警車。特別的是，我們提出一個無基礎設施 (Infrastructure-less) 的架構，此架構將包括追蹤模組 (Tracking module) 與回報模組 (Reporting module)，此方法架構將設計針對可疑車輛的追蹤與回報處理機制。對於追蹤模組的功能設計爲，在追蹤期間，必要時將把追蹤的工作換手 (Handoff) 至附近的車輛。此外，透過無需數位地圖 (Digital map) 的路口偵測 (Intersection detection) 機制完成回報到道路上附近的警車;對於回報模組的功能設計爲，利用協同式導引回報訊息至道路上最近警車的方法，以替代常用的氾濫式廣播 (Flooding) 訊息傳遞方式。而透過網路模擬 (Simulation) 的結果顯示，我們提出的方法架構可以避免不必要的重廣播 (Rebroadcast) 訊息，並可以有效地節省網路上訊息量的開銷。

關鍵字：特定短距通訊、車牌辨識、車載監控網路、車載追蹤、車載無線存取。

Surveillance On-the-Road: A Suspicious Vehicle Tracking and Reporting System Based on V2V Communications

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Submitted to College of Computer Science
Computer Science and Engineering
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ABSTRACT

The rapid progress of *Wireless Access in Vehicular Environment/Dedicated Short Range Communication (WAVE/DSRC)* and embedded surveillance system technologies has made vehicular surveillance networks possible. The vehicular surveillance network is a technology where video cameras are deployed on vehicles to monitor various phenomenons on the road. In this paper, each vehicle employs a video camera to identify suspicious vehicles (such as stolen cars) through *license plate recognition (LPR)* technologies. In addition, WAVE/DSRC-based radio interfaces are used to cooperatively track the identified suspicious vehicle and quickly report the discovery to nearby police cars via *vehicle-to-vehicle (V2V)* communications. In particular, we propose an infrastructure-less framework for suspicious vehicle tracking and reporting, which consists of a tracking module and a reporting module. The tracking module can handoff the tracking job to neighboring vehicles as necessary and detect intersection for reporting to nearby police cars without additional digital map. The reporting module can guide reporting messages to the nearest police car instead of flooding. Simulation results show that the proposed framework outperforms existing works, which can significantly reduce the control overhead by avoiding large amount of unnecessary rebroadcasts.

Keywords: Dedicated Short Range Communications, License Plate Recognition, Vehicular Surveillance Networks, Vehicle Tracking, Wireless Access in Vehicular Environments.

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Chapter 1

Introduction

The rapid progress of *Wireless Access in Vehicular Environment/Dedicated Short Range Communication (WAVE/DSRC)* and embedded surveillance system technologies has made vehicular surveillance networks possible. The vehicular surveillance network is a technology where video cameras are deployed on vehicles to monitor various phenomenons on the road, such as vehicle security [1], brake warning [2], and urban monitoring [3]. In this work, we focus on tracking suspicious vehicles and reporting to nearby police cars without costly infrastructures. Most existing works for these two purposes rely on roadside infrastructures and sensors [4–7].

For tracking purposes, reference [4] presents an architecture for vehicle tracking systems using wireless sensor technologies. Roadside units (RSUs) are installed along roads to continuously keep tracking vehicles at regular intervals. These RSUs are connected to the underlying wired infrastructure to receive queries from the central server and reply back with the necessary information. Reference [5] presents a wireless local area network (WLAN)-based real time system for vehicle localization. The proposed solution uses a neural network trained with a map of received power fingerprints from WLAN Access Points (APs) surrounding the vehicle. In these two works, however, a large number of RSUs and WLAN APs must be installed on the roadside to provide target information and received signal strengths to vehicles, respectively. Reference [7] proposes a smart parking scheme in VANETs, which includes the stolen vehicle tracking. When the thief drives the stolen vehicle along a road, all pass-by RSUs can detect the parking beacon sent from the moving vehicle. According to the parking lot's identifier in the beacon, it can report the position of the stolen vehicle to the parking lot. But as the same with [4] and [5], the stolen vehicle tracking is also achieved by the deployment of RSUs along roads.

For reporting purposes, reference [6] proposes a searching strategy called ANTS to locate a desire vehicle close to the query user, which is based on the lost ant searching for its nest. ANTS is employed in ShanghaiGrid [8] consisted of a large number of local nodes installed at crossroads, which is responsible for storing vehicle information and accepting queries. However, deploying such local nodes on each intersection requires a dramatic number of RFID readers and wireless APs and thus is costly. More importantly, it may not be practical to construct infrastructure in suburban and rural areas.

In particular, we propose an infrastructure-less framework for suspicious vehicle tracking and reporting, which consists of a tracking module and a reporting module. The tracking module can handoff the tracking job to neighboring vehicles if necessary and detect intersection for reporting to nearby police cars without digital map information. The reporting module can find the nearest police car at low message cost. It does not rely on costly roadside infrastructures and only relies on vehicle-to-vehicle (V2V) communications. On the other hand, traditional surveillance and tracking systems rely on roadside cameras for video recording. There are two problems associated with such solutions. First, it requires huge efforts to distinguish targets from many other candidates. Second, since targets are not predefined, the recorded images are usually not clear enough. Further, the volume of videos could be huge, thus requiring a lot of labors.

The rest of this paper is organized as follows. Chapter 2 defines the suspicious vehicle tracking and reporting problem. Chapter 3 describes our framework, which consists of a tracking module and a reporting module. Simulation results are presented in Chapter 4. Chapter 5 shows the prototype implementation. Finally, Chapter 6 concludes the paper.

Chapter 2

Problem Definition

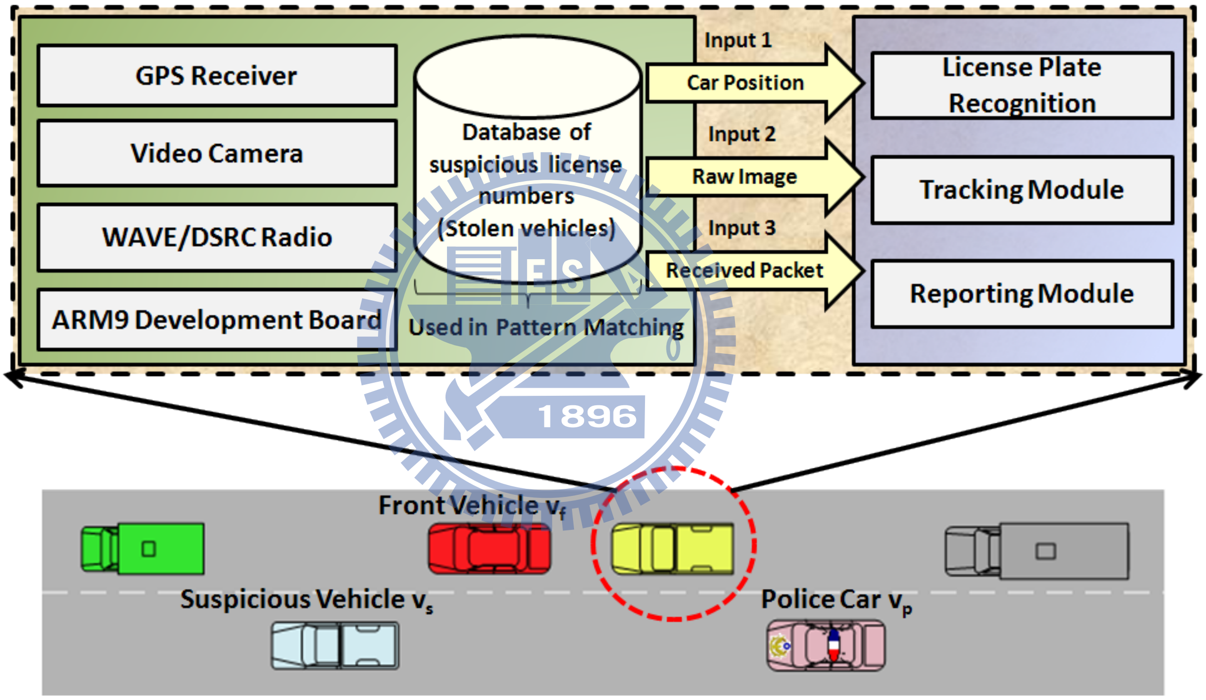

Figure 2.1: System architecture for suspicious vehicle tracking and reporting.

Figure 2.1 shows the system architecture for suspicious vehicle tracking and reporting. We consider vehicles on the roads that form vehicular surveillance networks via V2V communications. Each vehicle is equipped with a GPS receiver and a video camera. The GPS receiver serves to provide vehicle's own position. The video camera is to take/record the license plate pictures/videos of the immediate front vehicle. With license plate recognition (LPR) technologies, each vehicle can recognize the license plate number of its front vehicle. For identifying suspicious vehicles, recognized license numbers are compared with the suspicious vehicle database provided by the police department. Each vehicle has an

IEEE 802.11p [9] radio interface operating in the WAVE mode, which can dramatically reduces the connection setup overhead by discarding all association and authentication procedures. As long as vehicles operate in the same channel and use the wildcard Basic Service Set Identification (BSSID) composed of all "1s" in a 48-bit long field, they can immediately communicate with each other upon encounter on the road without having to join a BSS. Periodical beacons are used to obtain the IDs and positions of neighboring vehicles. In addition, TTL (time to live) is indicated in broadcasting messages to limit the number of their transmissions in vehicular surveillance networks.

The suspicious vehicle tracking and reporting (SVTR) problem is defined as follow. Each radio interface has a fixed transmission range of R. Each vehicle i has to identify whether the immediate front vehicle v_f is a suspicious vehicle v_s or not. There are two modes for LPR on the road that i recognizes v_f's license plate number every t_u and t_n seconds in the urgent mode and the normal mode, respectively. Before v_s has been identified, i recognizes the license plate number of v_f in the normal mode. Once v_f is identified as v_s, i will report this discovery to nearby police cars v_p and switch to the urgent mode to continuously recognize the license plate number of v_f to keep tracking v_s. If v_s is not in front of i due to changing its lane or direction, the tracking job will be handoff from i to i's neighboring vehicle immediate behind v_s.

Our goal is to design an efficient protocol for vehicles to cooperatively track the identified v_s. It addition, during the tracking process, we need to report the current position of v_s to v_p. Such reporting messages m_r should be guided to the nearest v_p and delivered through multi-hop forwarding. Therefore, v_p received these m_r can reconstruct the trajectory of v_s and arrive at the position of v_s as soon as possible to take further actions.

Chapter 3

Suspicious Vehicle Tracking and Reporting Framework

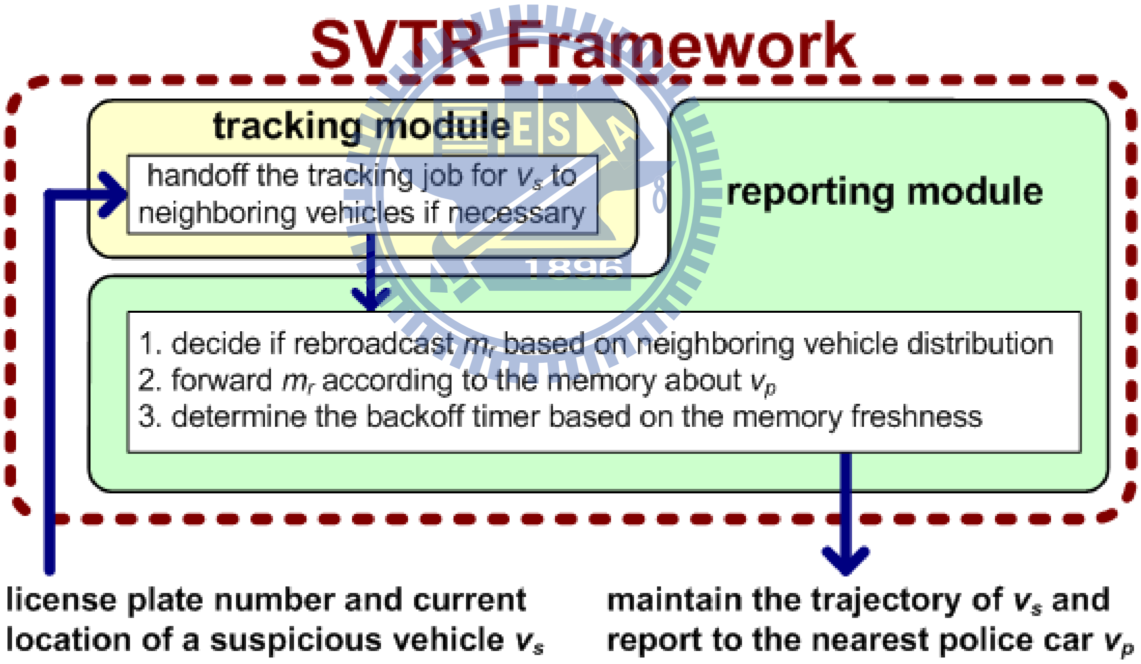

Figure 3.1: Components of the proposed framework.

In this section, we propose an infrastructure-less framework to solve the SVTR problem, which consists of a tracking module and a reporting module, as shown in Figure 3.1. First, to keep tracking the identified v_s, we propose tracking handoff and intersection detection schemes in Section 3.1. Second, to efficiently deliver reporting messages about v_s to the nearest v_p, rebroadcast decision,intersection-guiding search, and memory-based backoff schemes are presented in Section 3.2. Table 3.1 shows the summary of notations adopted in this section.

Table 3.1: Summary of notations.

notation	definition
v_s	the identified suspicious vehicle, such as a stolen car
v_f	the immediate front vehicle
v_p	the police car for dealing with v_s
m_h	the tracking handoff message sent to neighboring vehicles
m_r	the reporting message sent to nearby v_p
d_r	the reporting direction of m_r, which is from the sender to the receiver
d_b	the broadcast direction of m_r, which is specified by the sender
s_H	the sector located on the head of a vehicle
s_T	the sector located on the tail of a vehicle
s_R	the sector located on the right of a vehicle
s_L	the sector located on the left of a vehicle
s_C	one of s_H, s_T, s_R, and s_L to which m_r should be rebroadcasted
θ	the angles of s_H and s_T, whereas these of s_R and s_L are (180-θ)°
t_u	the LPR interval in the urgent mode
t_n	the LPR interval in the normal mode
t_i	the passing time from vehicle i met v_p to now
τ	the parameter to define the backoff window of vehicles met v_p the most recently
ρ	the number of backoff classes
T	the valid duration of vehicles' memory about v_p

3.1 Tracking Module

In vehicular surveillance networks, through the onboard camera, each vehicle i can take snapshots on its v_f. i retrieves these license plate numbers and compares them against a database of suspicious plate numbers provided by the police department (through the Internet or nearby police cars). When a suspicious vehicle v_s is identified, i will continuously take snapshots on its v_f to keep tracking the identified v_s. For cooperatively tracking v_s, we design a tracking handoff scheme to pass the tracking job to the neighboring vehicle immediate behind v_s due to v_s changes its lane or direction. In addition, for reconstructing the trajectory of v_s, we design an intersection detection scheme to report the current position of v_s to v_p on each intersection during the tracking process.

3.1.1 Tracking Handoff Scheme

If vehicle i detects its v_f as v_s in the normal mode, i will switch to the urgent mode to keep tracking v_s. Once i can not detect v_s in the urgent mode, i will broadcast a tracking handoff message m_h to neighboring vehicles. Vehicles received m_h will switch from the normal mode to the urgent mode for detecting the missed v_s. The neighboring vehicle j detected v_s will take over the tracking job from i, and other neighboring vehicles will switch to the normal mode after the predefined period from the urgent mode. Similarly, once j can not detect v_s in the urgent mode, j will repeat the above procedures taken by i. For example in Figure 3.2, A is a tracking vehicle in the urgent mode and B is a suspicious vehicle tracked by A. Once A can not detect B in the urgent mode, A will broadcast m_h to C and D. C and D will switch from the normal mode to the urgent mode for detecting B. On one hand, since C has detected B, the tracking job is handoff from A to C. On the other hand, after the predefined period in the urgent mode, D will switch back to the normal mode.

3.1.2 Intersection Detection Scheme

As shown in Figure 3.3, the outer circle is the transmission range of each vehicle i and the inner circle is a controlled parameter based on the vehicle density to filter nearby vehicles. The transmission range is divided into four sectors according to i's driving direction. The head, tail, right, and left of i are the sectors s_H, s_T, s_R, and s_L, respectively. Angles of s_H and s_T are defined as $\theta°$ whereas those of s_R and s_L are defined as (180-θ)°. Note that the inner circle area is not included in all sectors.

Since every vehicle periodically sends a beacon message contained its position information, i can maintain the neighboring vehicle distribution in its transmission range. In addition to position information, v_p also announces its identifier in its beacon message.

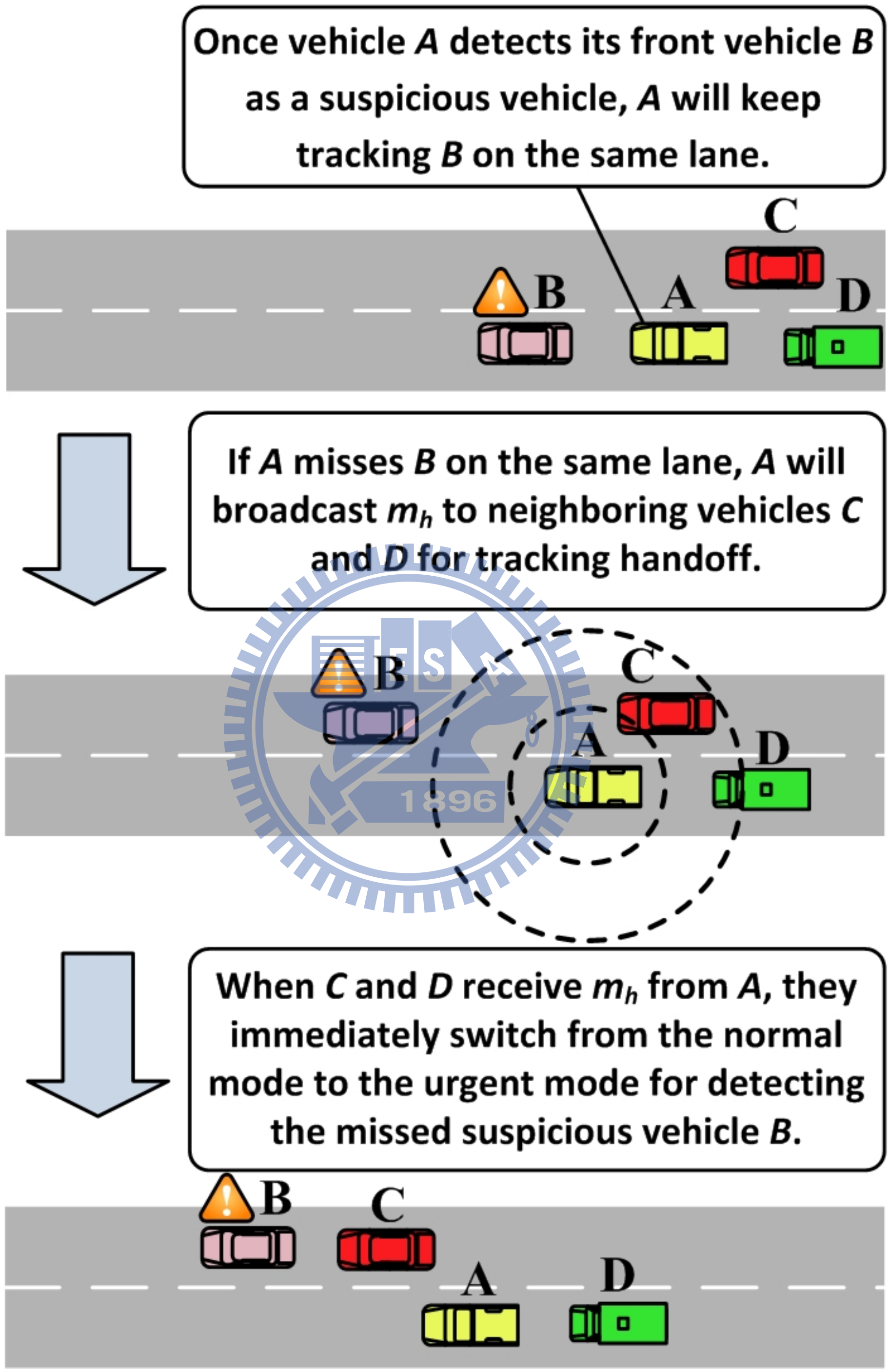

Figure 3.2: Handoff the tracking job to neighbor vehicles if necessary.

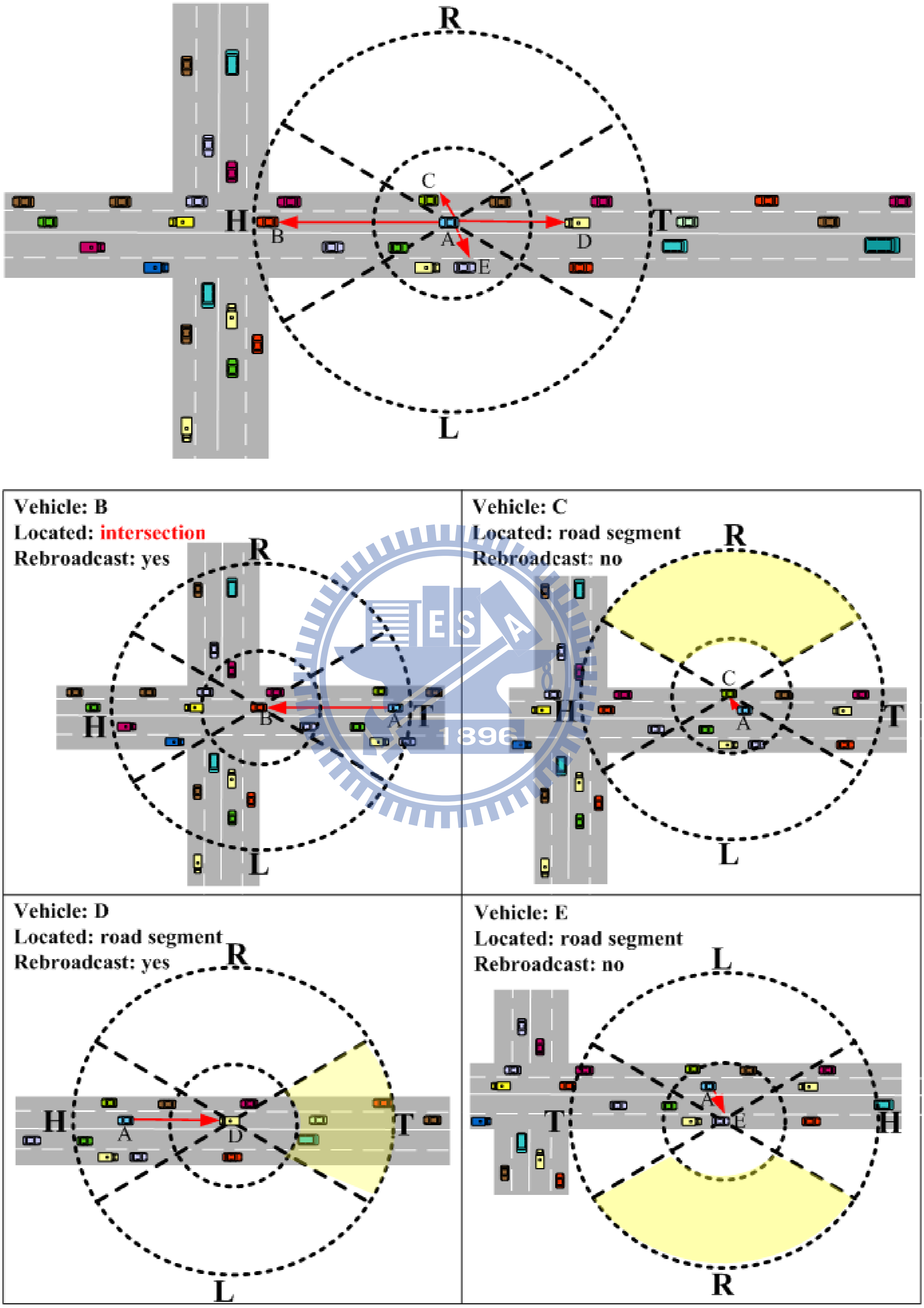

Figure 3.3: Rebroadcast decision based on the neighboring vehicle distribution.

0 : No vehicle
1 : Vehicle presence
X : Don't care

S : Road segment
I : Intersection

S_R	S_H	S_L	S_T	Locate
0	X	0	X	S
1	X	0	X	I
0	X	1	X	I
1	X	1	X	I

Figure 3.4: Summary definitions of intersection detection

Thus, other vehicles met v_p can record the time and position information from v_p's beacon message. Since all positions of i's neighboring vehicles can be obtained from received beacon messages, i can determine whether there are neighboring vehicles in its s_H, s_T, s_R, and s_L.

By checking if each sector has neighboring vehicles, i can detect that itself is on intersection or road segment. For example, if there is no neighboring vehicle in s_R and s_L, it implies that i is located on road segment. Conversely, if there are neighboring vehicles in either s_R or s_L, it implies that i is located on intersection. For example in Figure 3.3, vehicle A, C, D, and E is on road segment whereas vehicle B is on intersection. Note that the corner (i.e., there are neighboring vehicles in two adjacent sectors) will also be detected as intersection in our scheme since it consists of two road segments with different directions.Figure 3.4 shows the Summary definitions of intersection detection.

3.2 Reporting Module

Once v_s is identified by vehicle i, the discovery should be reported to the nearest v_p via V2V communications. Thus, after the nearest v_p receives m_r sent by i, it can take less time to arrive at the position of v_s. In particular, the proposed reporting module for this purpose has diverse applications. For example, a driver wants to report an accident to an ambulance car. Obviously, an ambulance car close to the accident location is more preferable. Flooding is an intuitive search scheme that can always find the nearest v_p. However, it produces a huge amount of network traffic and thus its scalability is low.

To reduce the control overhead for reporting m_r to nearby v_p, we design rebroadcast decision, intersection-guiding search, and memory-based backoff schemes to minimize the number of m_r rebroadcasts, where m_r contains the discover's ID, v_s's position and license number, and a sequence number.

3.2.1 Rebroadcast Decision Scheme

In this scheme, vehicles decide whether rebroadcast m_r according to their positions and m_r's reporting direction d_r. The rebroadcast decision is made as follows.

1. Once vehicle i identifies the license plate number of v_s, i will immediately send m_r to nearby v_p. When vehicle j receives m_r sent by i, j first detects its location type according to its neighboring vehicle distribution. If j is located on intersection, it will rebroadcast m_r immediately. On the contrary, if j is located on road segment, it will detect d_r based on the sender's position and check whether the corresponding sector s_C for d_r has neighboring vehicles. If j's s_C for d_r has neighboring vehicles, m_r will be rebroadcasted by j. Otherwise, m_r will be discarded to avoid unnecessary rebroadcasts since there is no neighboring vehicle in j's s_C for d_r. For example in Figure 3.3, the sender A is located on s_T of B so that d_r is from s_T to s_H and thus s_C for d_r is s_H.

2. Similarly, after other vehicles receive m_r from i, they first detect their location types. On one hand, for the vehicle located on intersection, it will rebroadcast m_r to the vehicles on all its sectors. On the other hand, for the vehicle located on road segment, it decides to rebroadcast according to whether there are neighboring vehicles in its s_C for d_r. For example in Figure 3.3, based on the current position and d_r, vehicle C and E decide not to rebroadcast m_r because there is no neighboring vehicle in their s_Rs whereas vehicle D decides to rebroadcast m_r since D's s_T has neighboring vehicles.

3.2.2 Intersection-guiding Search Scheme

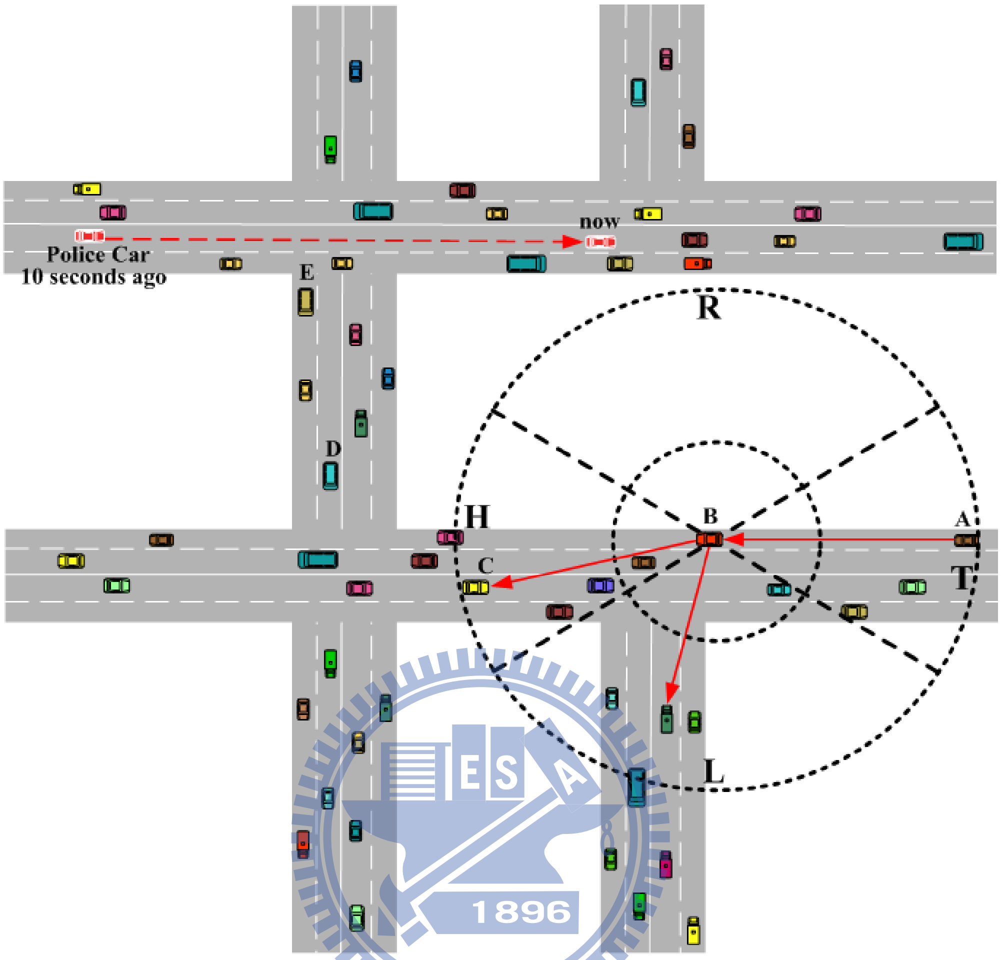

Figure 3.5: Reporting the suspicious vehicle discovery to nearby police cars.

Based on the above rebroadcast decision scheme, we further develop an intersection-guiding search scheme, which m_r is guided to the nearest v_p as follows.

1. At the beginning in Figure 3.5, vehicle A identifies v_s and reports m_r to the nearest v_p. There are four intersections traveled by m_r from A. Vehicle B is located on the first intersection, vehicle C and D are located on the second intersection, and vehicle E is located on the third intersection.

2. On the first intersection in Figure 3.6, vehicle B can detect that m_r is from s_T (i.e., from A to B) and that B itself is located on intersection. Moreover, B did not meet v_p before. So B decides to rebroadcast m_r without specifying the broadcast direction d_b (i.e., denoted by "broadcast to: s_C" instead of "s_H", "s_T", "s_R", or "s_L").

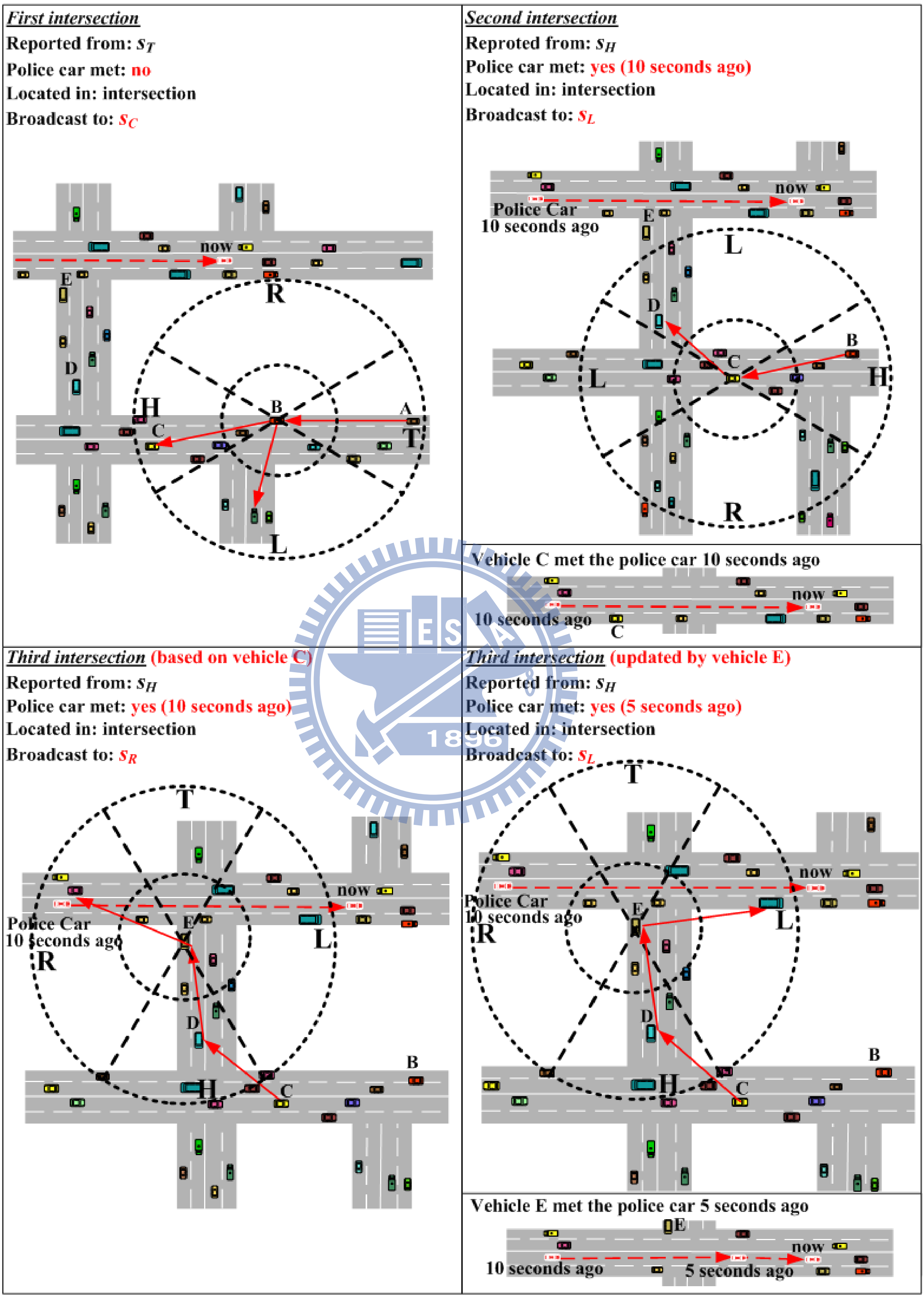

Figure 3.6: Procedures of the intersection-guiding search scheme.

Therefore, each vehicle located on the first intersection receiving B's rebroadcasted m_r will decide its d_b by itself.

3. On the second intersection in Figure 3.6, vehicle C can detect that m_r is from s_H (i.e., from B to C) and that C itself is located on intersection. In particular, C has met v_p 10 seconds ago. So C guides m_r to its s_L, which is closest to the recorded position of v_p 10 seconds ago. Thus, only the neighboring vehicles in C's s_L will try to rebroadcast m_r from C. Those neighboring vehicles in other three sectors will discard m_r immediately because d_b of m_r has been specified (i.e., denoted by "broadcast to: s_L"). Note that d_b specified by C is the related direction between C's position and the past position of v_p in C's memory.

4. On the third intersection in Figure 3.6, vehicle E can detect that m_r is from s_H (i.e., from D to E) and that E itself is located on intersection. Based on the C's memory for v_p, m_r should be rebroadcasted to s_R of E. However, E has met v_p 5 seconds ago, which is more up-to-date than C. So m_r will be guided to s_L according to E's memory for v_p. Therefore, v_p can be found without rebroadcasting m_r to other road segments on intersection.

Since d_b can be guided on intersection by vehicles' memory for v_p, the flooding of m_r can be intelligently avoided and converted to an unidirectional forwarding. Thus, the number of rebroadcasted m_r can be significantly reduced by the proposed intersection-guiding search scheme, which also can minimize the reporting delay caused by message collisions.

3.2.3 Memory-based Backoff Scheme

In IEEE 802.11p [9], the Enhanced Distributed Channel Access (EDCA) originally provided by IEEE 802.11e is employed for prioritized channel access. It is accomplished by using different channel access parameters for each packet priority, which there are four access categories defined for background (AC_BK), best effort (AC_BE), video (AC_VI), and voice (AC_VO) traffic. A backoff scheme is adopted in EDCA, which consists of Arbitration Interframe Space Number (AIFSN) and a random backoff timer. AIFSN

Table 3.2: Default EDCA parameter set.

AC	CW_{min}	CW_{max}	AIFSN
AC_BK	aCW_{min}	aCW_{max}	9
AC_BE	$(aCW_{min}+1)/2-1$	aCW_{min}	6
AC_VI	$(aCW_{min}+1)/4-1$	$(aCW_{min}+1)/2-1$	3
AC_VO	$(aCW_{min}+1)/4-1$	$(aCW_{min}+1)/2-1$	2

is a fixed waiting time in unit of slot, whereas the backoff timer is a random waiting time selected from a Contention Window (CW). The CW size is initially set to CW_{min} and doubled until reaching CW_{max} after each transmission collision. The default EDCA parameter set of IEEE 802.11p is shown in Table 3.2. In our scheme, m_r is assigned to AC_VO with the smallest AIFSN and a memory-based backoff timer.

To reduce the number of m_r rebroadcasts, we design a memory-based backoff scheme to make the receiver met v_p the most recently be the first rebroadcasting guider without any central control. When vehicle i receives m_r, i first decides to rebroadcast it or not. If i decides to rebroadcast m_r, i will be assigned a backoff timer based on the passing time t_i from i met v_p to now. If i never met v_p before, t_i will be set to ∞. Thus, i with the smaller t_i can get the smaller backoff timer, which is shown as follows:

$$BT_i = \begin{cases} [0, 2^{\tau+1} - 1] & 0 < t_i \leq \frac{1}{\rho}T \\ [2^{\tau+1}, 2^{\tau+2} - 1] & \frac{1}{\rho}T < t_i \leq \frac{2}{\rho}T \\ \vdots & \\ [2^{\tau+\rho-1}, 2^{\tau+\rho} - 1] & \frac{\rho-1}{\rho}T < t_i \leq \infty \end{cases},$$

where τ is the parameter to define the backoff timer of vehicles met v_p the most recently, ρ is the number of backoff classes, and T is the valid duration of vehicles' memory about v_p. Thus, receivers with the more up-to-date memory for v_p can easily select the smaller backoff timers so that one of them can be the first rebroadcasting guider. In addition, an implicit acknowledgement (ACK) strategy is adopted to eliminate redundant m_r, in which the reception of m_r with the same sequence number serves as an implicit ACK. On receiving an implicit ACK, vehicles received m_r do not need to rebroadcast it. There is no retransmission for any collided m_r from a rebroadcasting guider. So m_r with the same sequence number will not be retransmitted at any rebroadcasting guider even it collides with other control messages or data packets. In order to prevent that no rebroadcasting guider successfully rebroadcasts m_r, the backoff timer of the sender is set to $2^{\tau+\rho}$. Once the sender backs off to 0, it sends m_r with a new sequence number to differentiate an implicit ACK.

From the above expression, it is clear that the backoff timer is chosen based on the memory for v_p of the receiver. Vehicle i with the smallest t_i may choose the smallest BT_i and thus has a chance to rebroadcast and guide m_r earlier than all the other receivers. When other receivers detect the rebroadcasting of m_r with the same sequence number, all of them refrain from rebroadcasting. In this way, the memory-based backoff scheme efficiently reduces the number of m_r rebroadcasts as well as the probability of message collisions.

Chapter 4

Performance Evaluation

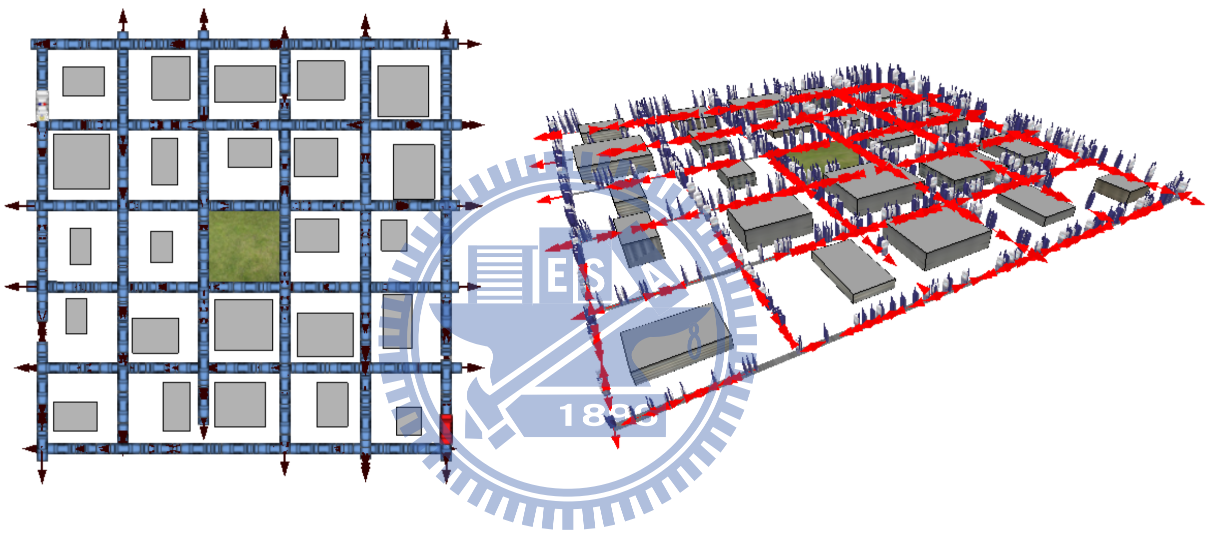

Figure 4.1: Urban topology used in the experiments.

The proposed suspicious vehicle tracking and reporting framework is implemented in the QualNet 5.0 [10] simulator with necessary modifications. The performance is evaluated in a $5km^2$ urban area, which each building block is $1km^2$, as shown in Figure 4.1. Vehicles are uniformly placed on each road segment and their directions are randomly selected on each intersection. Basic parameters used in our simulation are summarized in Table 4.1. We set $t_u = 1$ s, $t_n = 10$ s, $\tau = 1$, $\rho = 3$, and $T = 30$ s. In the following evaluation, total number of reporting messages and reporting delay to the police car are addressing in the comparison of the proposed framework, the flooding scheme, and the intelligent broadcast scheme [11].

Figure 4.2 illustrates the total number of reporting messages under different number of vehicles. We set the total number of vehicles as 750, 1000, 1250, 1500, and 1750. Both

Table 4.1: Simulation parameters

Parameter	Value
Number of Vehicles	750 ∼ 1750 vehicles
Vehicle Speed	40 km/hr ∼ 60 km/hr
MAC Protocol	IEEE 802.11a
Radio Model	Two ray ground
Routing Protocol	Broadcast forwarding
Reporting Message Size	128 bytes
Communication Range	300 m

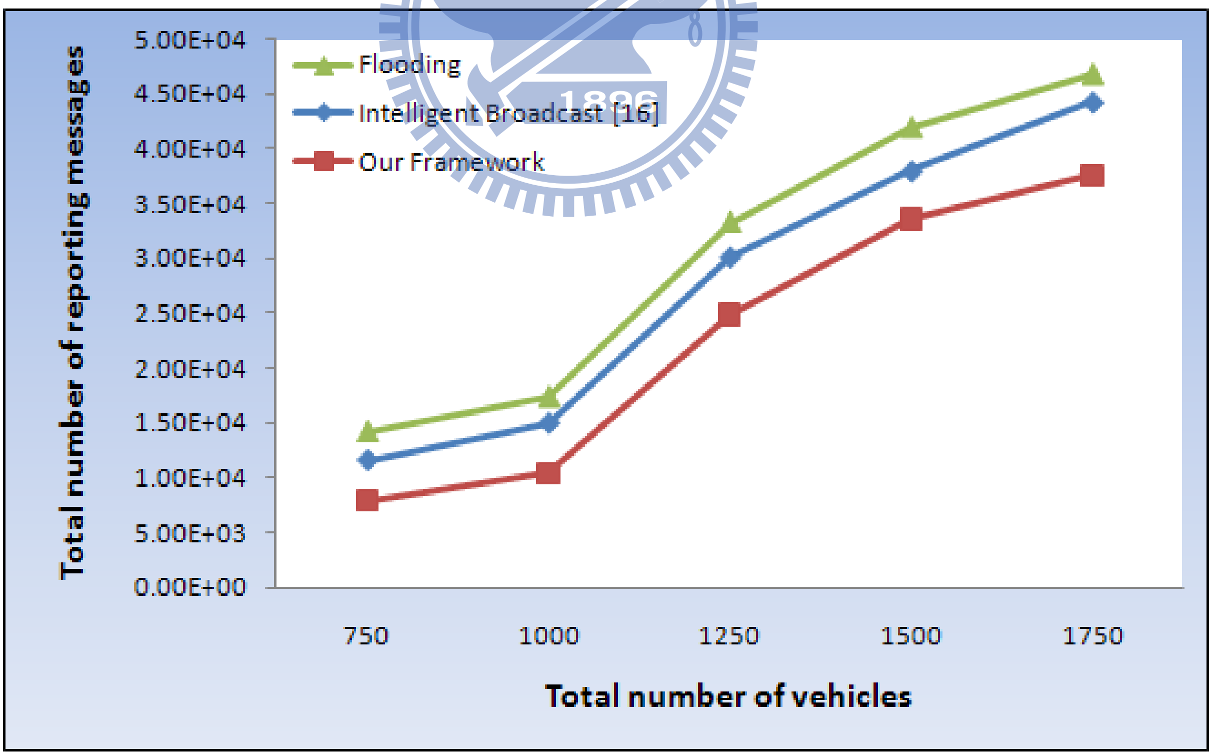

Figure 4.2: Comparison of total number of reporting messages.

the suspicious car and the police car are randomly selected. From Figure 4.2, we can observe that our framework has the lowest number of reporting messages. This is because our reporting module may guide reporting messages on each intersection by the memory of vehicles for the police car, which only one road segment is needed to be rebroadcast. On the contrary, flooding and intelligent broadcast will rebroadcast all road segments on each intersection so that their total numbers of reporting messages increase with the total number of vehicles.

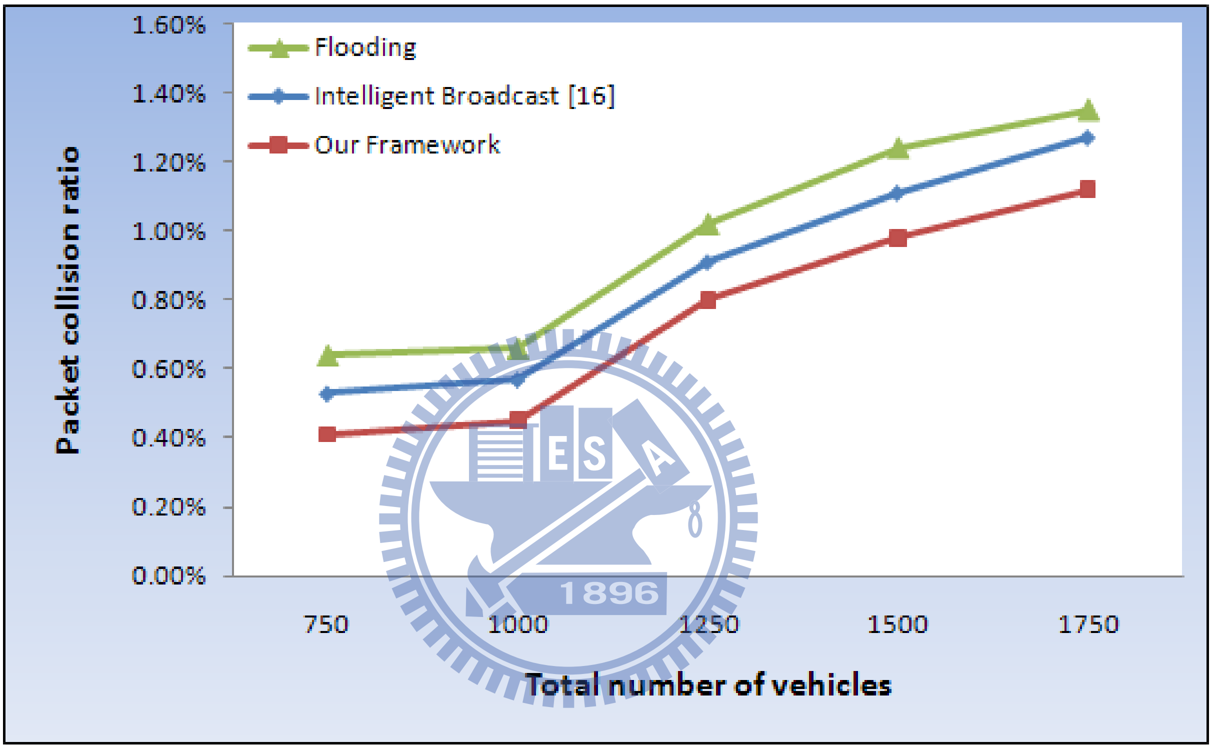

Figure 4.3: Comparison of packet collision rate.

Figure 4.3 shows the packet collision ratio under different number of vehicles on the roads, which the suspicious car and the police car are randomly selected. From Figure 4.3, we can observe that the packet collision rate of our framework is lower than those of intelligent broadcast and flooding. This is because flooding broadcasts many reporting messages so that the probability of transmitting packets at the same time becomes higher, as well as intelligent broadcast. The situation becomes worse when the total number of vehicles increases. On the contrary, our framework only needs to transmit reporting packets to those vehicles closer to the police car, which the number of vehicles in one road segment is lower than the number of vehicles in all road segments on each intersection. In addition, the memory-based backoff scheme in our framework further reduces the packet collision rate.

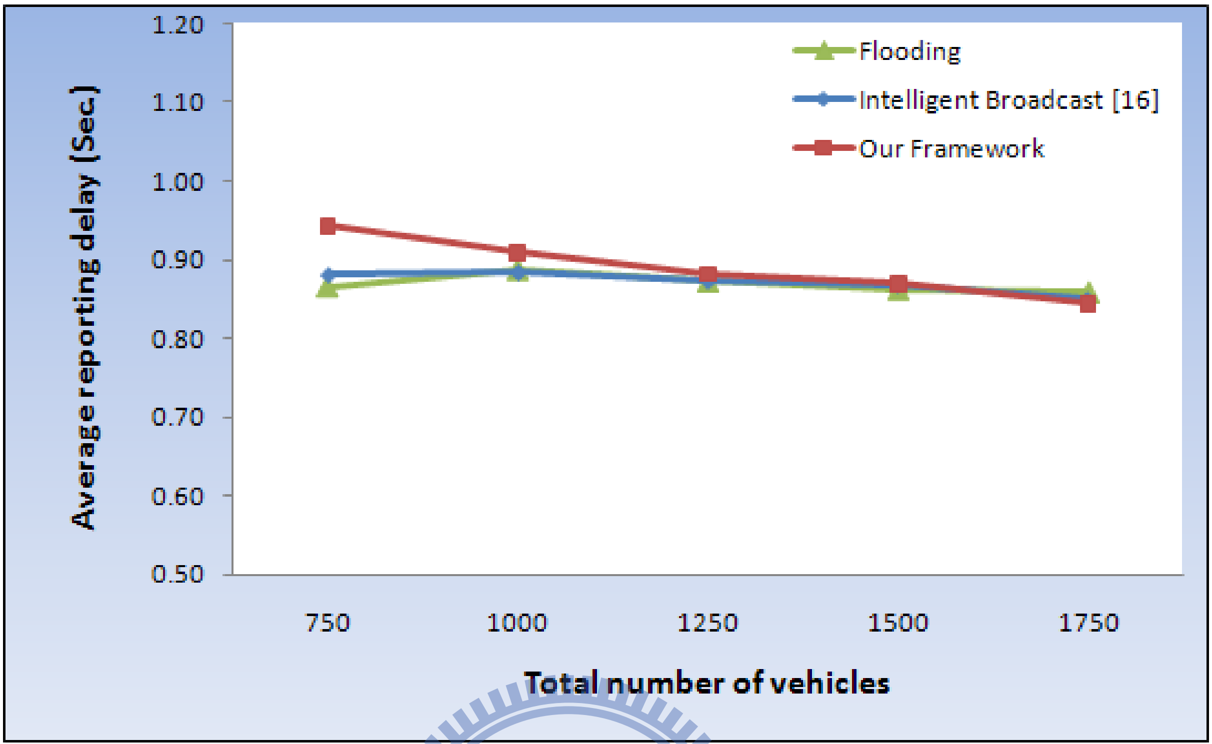

Figure 4.4: Comparison of average reporting delay to the police car.

Figure 4.4 shows the average reporting delay to the police car for various numbers of vehicles on the roads. As the same with Figure 4.2 and Figure 4.3, both the suspicious car and the police car are randomly selected. In Figure 4.3, our framework has the similar reporting delay with intelligent broadcast and flooding as the total number of vehicles increases. Since the proposed framework only needs to rebroadcast reporting messages to one road segment instead of all on intersection, it can produce the similar reporting delay while keeping the reporting cost low. On the other hand, Figure 4.5 shows the handoff success rate under different number of vehicles and handoff tracking duration, which varied from 750 to 1750 and from 5 to 30 seconds, respectively. The handoff success rate increases from 36% to 97% as the total number of vehicles and handoff tracking duration increase.

From these results, we conclude that the proposed framework can achieve the lowest number of rebroadcast packets and packet collision rate while keeping the average reporting delay similar with existing works. It is leading to more efficient use of wireless bandwidth. On the other word, adopting our framework in vehicular networks can

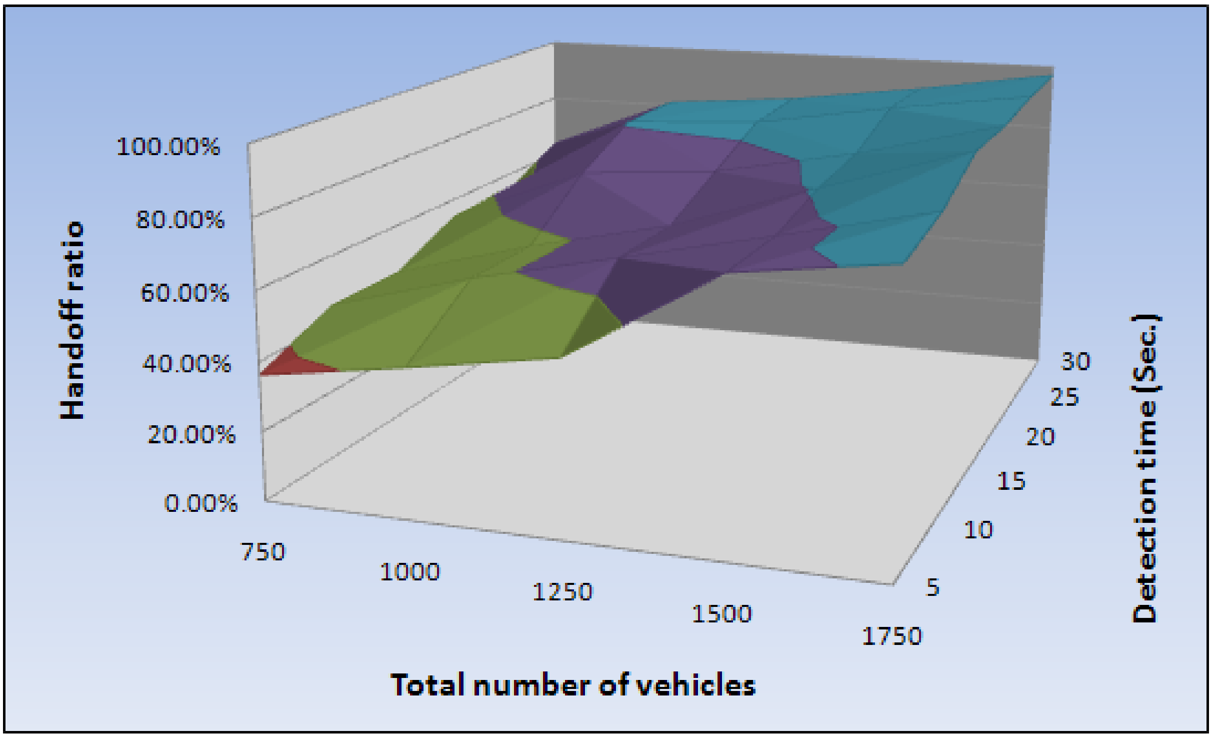

Figure 4.5: Handoff success rate under different number of vehicles and tracking handoff duration.

both avoid the transmission of reporting messages wasting bandwidth due to unnecessary rebroadcasts and prevent reporting messages from collision caused by serious packet contention.

Chapter 5

Prototype Implementation

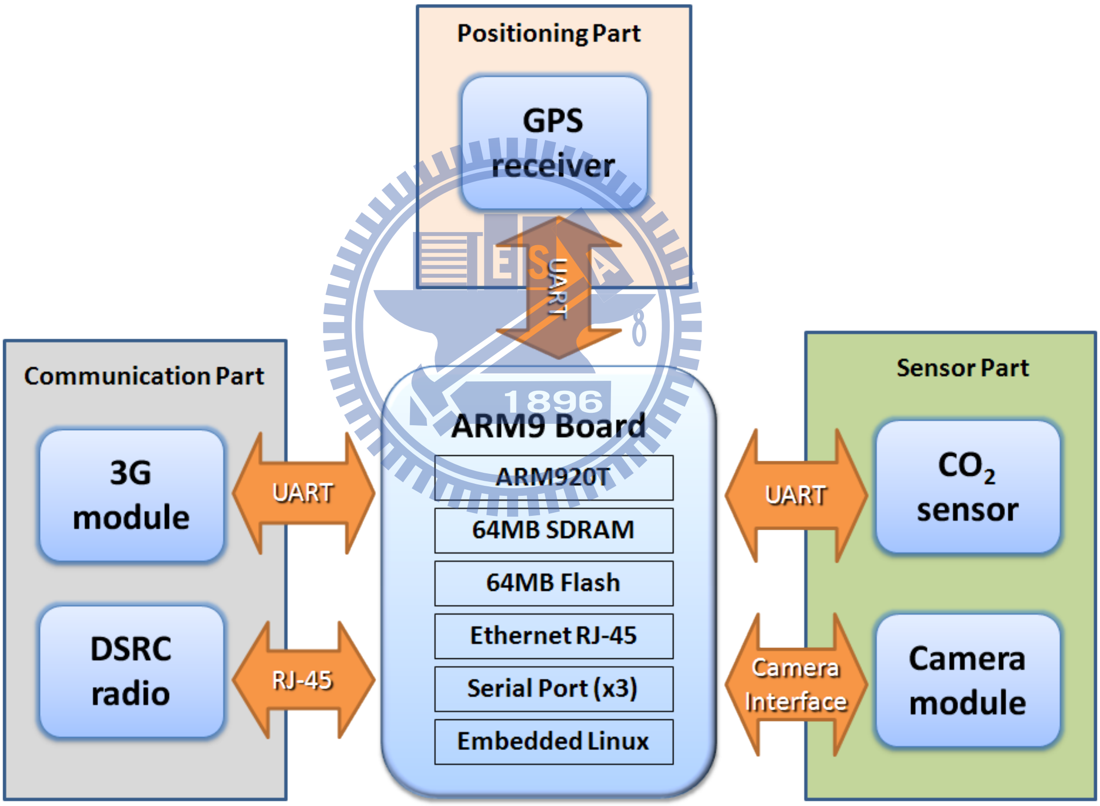

Figure 5.1: Building blocks of VS^3.

We have developed a prototype for the proposed suspicious vehicle tracking and reporting system, called Vehicular Surveillance and Sensing System (VS^3). Figure 5.1 shows its building blocks. In addition to suspicious vehicle tracking and reporting, we add a CO_2 sensor and a 3G module for car security extensions [1]. The camera module and WAVE/DSRC radio are connected to the microprocessor via build-in Camera Interface and Ethernet RJ-45 interface, respectively, whereas the other modules are mounted through the UART interfaces. Below, we describe implementation details.

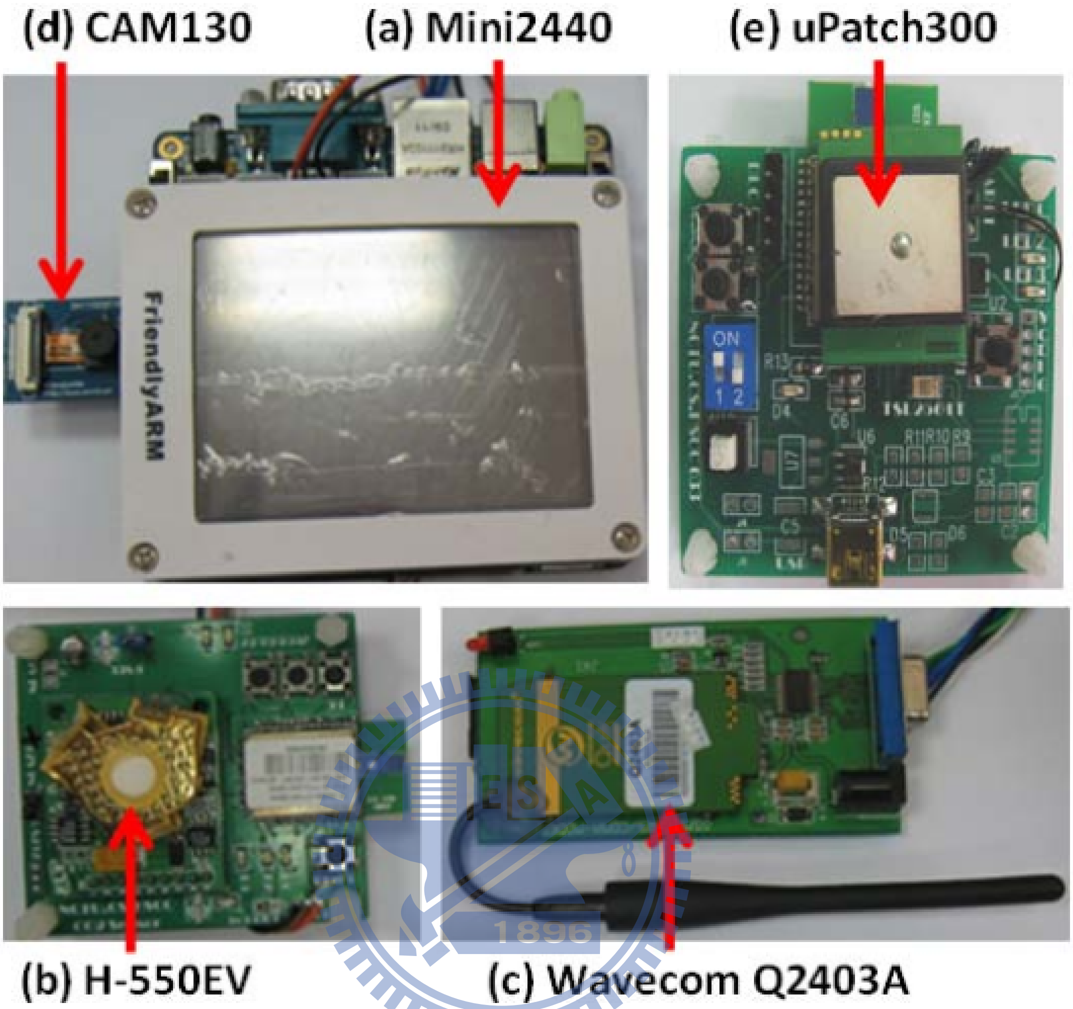

Figure 5.2: Hardware components of VS^3.

5.1 Microprocessor

The microprocessor in the car unit is an ARM9 board (Mini2440 [12]) with a 3.5" TFT LCD as shown in Figure 5.2(a), which has a 400MHz 32-bit RISC integer processor (ARM920T [13]), 64MB SDRAM, 64MB Nand Flash, Camera Interface, three serial ports, a 10/100M Ethernet RJ-45, and built-in microphone. In particular, Mini2440 can run embedded Linux and WinCE to develop diverse applications. During the development stage, Linux with an arm-linux-gcc compiler is installed first. Then, the ARM9 board is connected to a PC through the RS-232 interface.

5.2 Camera Module

Figure 5.2(d) shows the camera module CAM130, a CMOS optical sensor. It receives snapshot commands from Mini2440 and takes full-resolution pictures to Mini2440 through the Camera Interface. Similar to the CO_2 Sensor, a character device (such as "/dev/camera") in Linux must be opened to get the video data. An array is declared to store data from the character device. Through the Linux framebuffer mechanism, the video data can be copy to the mapped memory space and displayed on the TFT screen.

To output the video data captured from the camera to an image file, the jpeg library, *libjpeg*, is linked to the executable program. It also transforms the 16-bit color images to the 24-bit color format (RGB888). Moreover, the color compensation of RGB bytes is adopted to make images clearer.

5.3 GPS Receiver

The GPS module is implemented by uPatch300 [14] with the embedded GPS antenna as shown in Figure 5.2(e), which follows NMEA (National Marine Electronics Association) 0183 protocol. It uses SiRFstarIII chip with high sensitivity to provide geographic information to locate positions of vehicles.

5.4 WAVE/DSRC Radio

The WAVE/DSRC module is implemented by ITRI WAVE Communication Unit (IWCU [15]), which is connected by Ethernet RJ-45 with Mini2440. It has two IEEE 802.11p [9] interfaces and one Ethernet connector. Vehicular applications developed in Mini2440 can just send UDP packets via standard Linux socket APIs (e.g., bind(), sendto(), and recvfrom()). IWCU can convert UDP packets to WSMP (WAVE short message protocol)

5.5 CO_2 Sensor

The CO_2 module has a H-550EV CO_2 sensor [16] integrated with Jennic JN5139 [17], which is mounted to Mini2440 via an UART interface. Our prototype is shown in Figure 5.2(b). The CO_2 sensor module has 0∼5,000 ppm measurement range and ±30ppm accuracy. JN5139 has a 16MIPs 32-bit RISC processor, a 2.4GHz IEEE 802.15.4-compliant transceiver, 192kB of ROM, and 96kB of RAM. In particular, JN5139 allows the flexibility of supporting mesh networking and packet routing inside a vehicle. To obtain sensing data from the CO_2 sensor, a character device (such as "/dev/ttySAC#") in Linux is opened to read/write data from/to the serial port.

5.6 3G Module

We adopt the Wavecom Q2403A GSM/GPRS/CDMA module as shown in Figure 5.2(c), which is controlled by Mini2440 via AT commands. It performs SMS, MMS, and video calls as instructed by the ARM9 board. To send a short message, AT commands are issued to control GSM/GPRS modem.

5.7 Demonstration

For *license plate recognition* (LPR), we integrate a software with the following functions: plate localization, plate orientation and sizing, normalization and edge detection, character segmentation, and optical character recognition. For suspicious car tracking and reporting, we demonstrate that the license plate picture of a vehicle is taken in a model car as shown in Figure 5.3(a), and it has been recognized as a suspicious vehicle as shown in Figure 5.3(b). Figure 5.3(c) and Figure 5.3(d) show our prototyping system set up in a real car and a suspicious vehicle tracking scenario, respectively.

Figure 5.3: Prototyping demonstration.

Chapter 6

Conclusion

This paper integrates WAVE/DSRC communications into surveillance technologies to support suspicious vehicle tracking and reporting applications without costly roadside infrastructures. Vehicles on the road form a vehicular surveillance network for tracking a suspicious vehicle and reporting the discovery to the nearest police car. We propose an infrastructure-less framework for suspicious vehicle tracking and reporting based on V2V communications, which consists of a tracking module and a reporting module. The tracking module can handoff the tracking job to neighboring vehicles if necessary and detect intersection for reporting to nearby police cars without digital map information. The reporting module can find the nearest police car at low message cost. The proposed framework can significantly reduce the control overhead by avoiding large amount of unnecessary rebroadcasts.

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