行政院國家科學委員會補助專題研究計畫 □成果報告
■期中進度報告

異質網路環境之行動搜尋關鍵技術-子計畫一:
車用隨意網路存取控制與連結機制之研究(2/3)

計畫類別：□ 個別型計畫　■ 整合型計畫
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成果報告類型(依經費核定清單規定繳交)：■精簡報告　□完整報告

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執行單位：國立交通大學資訊工程學系(所)

中華民國 98 年 5 月 31 日

中文摘要：

本子計畫為期三年，主要研究目標在於發展VANET 網路之存取控制協定(Media Access Control, MAC)及連結機制(Connectivity Support)。

隨著無線通訊網路技術的進步，各國政府紛紛投入智慧型運輸系統(ITS)的研究。車用隨意網路(VANET)，為當前了為實現 ITS 所發展出重要網路架構。緊急訊息廣播機為VANET 下重要的應用，當緊急事件發生時，偵測到事故的車輛會產生一個緊急訊息並將些訊息廣播出去，在這同時其中一台接收訊息的車輛會被選作轉送者來進行訊息的轉送，直到此訊息已傳達到風險區的邊緣，然而如果沒有適當的選者轉送者，將會造成過多的車輛參與轉送，使得資料通道的競爭和資料封包碰撞問題變的嚴重，進而導致較高的延遲時間和傳輸失敗率。另一方面，為了避免資料封包的碰撞，轉送者在接收到訊息後，通常會等待一段隨機的時間才進行轉送，這段等待時間也會增加傳輸的延遲。

此外，高速公路電子收費系統(ETC)為 ITS 重要的應用。目前 ETC 的通訊主要是以專用短距通信技術(DSRC)。有數種媒介可作為 DSRC 的基礎，其中車用環境無線取技術(WAVE)，提供快速移動車輛一個多頻道(multi-channel)的運作架構，能使車上設備(on-board unit, OBU)與路側設備(roadside unit, RSU)快速的在行車環境中建立車對車(V2V)以及車對路側(V2R)的通訊。

有鑑於此，本子計畫第二年的研究主題有二: (1) 提出了一個以車輛密度為基礎的緊急訊息廣播機制(vehicle-density-based emergency broadcast scheme)，簡稱 VDEB。這個架構主要的概念是透過預估周邊車輛的密度，來減少參與競爭轉送者的數量，並同時降低轉送時所需的等待時間。這個架構也只需要有較少的控制負載(control overhead)，就能達成穩定的運作。(2) 著手於 WAVE/DRSC 多車道自由流動(MLFF) ETC 系統的設計，利用WAVE/DRSC 多重通道的特性，提供高車流環境中穩定且快速的交易需求。

關鍵詞： **車用隨意無線網路、緊急訊息廣播、電子收費系統、多重通道**

英文摘要：

The goal of subproject 1 is to provide the medium access control mechanism and connectivity support for vehicle ad-hoc networks.

The extension of wireless technology, vehicular ad hoc network provides general data transmission services and emergency warning services. To rescue more drivers from being involved in an emergency event on the road, fast emergency message propagation is an important issue. There are two types of broadcasting forwarder selection scheme, known as sender-oriented schemes and receiver-oriented schemes. The former maintains neighboring information to choose the best forwarder before broadcasting the message while the later distributed elects the forwarders. To solve the problem of high overhead in sender-oriented scheme and long delay in receiver-oriented scheme, we proposed a vehicle-density-based emergency broadcast (VDEB) scheme in this project.

On the other hand, the development of electron tolling collection (ETC) system is the tendency in many countries, which is primarily based on the dedicated short range communication (DSRC). There are several techniques that can be employed to realize the DSRC. In particular, the wireless access for vehicular environment (WAVE) provides multi-channel access to enable reliable and fast communication in vehicular network. For this reason, we intend to develop a multi-lane free-flow ETC system based on the multi-channel character of the WAVE/DSRC.

**Keywords: Vehicle Ad-Hoc Network, Emergency Message Broadcasting, ETC.
Multi-channel**

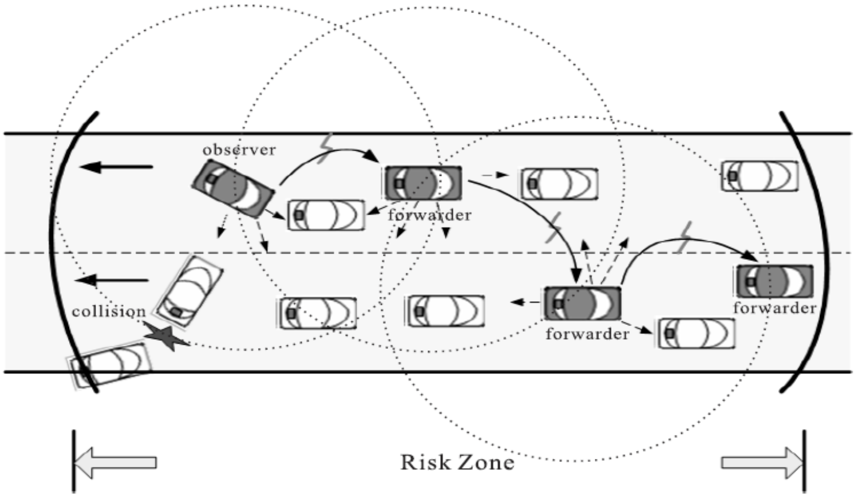
一、 前言

隨著無線通訊網路技術的進步，加上電子元件價格漸漸下降以及行車安全問題越來越受重視，各國政府紛紛投入智慧型運輸系統(Intelligent Transport Systems, ITS)的研究[1-7]。ITS 為應用先進的電子、通信、資訊與感測等技術，以整合人、路、車的管理策略，其主要的目地為提供即時(real-time)的資訊，並增進運輸系統的安全、效率及舒適性，同時也減少交通對環境的衝擊。

車用隨意網路(Vehicle Ad-hoc Network, VANET)，為當前了為實現 ITS 所發展出重要網路架構[8]。在個架構下，每一個搭載無線通訊設備的車輛，都可以透過路旁的路側系統(Road Side Unit, RSU) 連線到 Server 端索取所需的資訊。而當車輛距離基地台太遠超出傳訊範圍時，也可透過其它的車輛幫忙轉送。換句話說，每一個車輛都可視為是一部行動無線路由器(mobile wireless router)。因此，這樣的架構可大幅提升網路建置彈性，只要有車輛的地方，即可是 VANET 的涵蓋範圍。

車用隨意網路的應用主要可以分為兩類: (1)一般資料傳送服務(general data transmission services); (2)安全服務(safety services)。前者提供一對一資料路由(one-to-one data routing)或一對多資料廣播(one-to-all data broadcasting)服務，例如娛樂相關、路徑規劃等。這類應用著重於高穩定高頻寬的傳輸需求。後者則是在限定區域內提供一對多的緊急訊息廣播(one-to-all emergency message broadcasting)服務，例如電子煞車系統(electronic brake light)、車道切換輔助(lane changing assist)、路況報導(road condition reports)等。這類應用通常是與生命安全息息相關的(life critical)，因此訊息不只是要能成功的被接收還要在極短的時間內到達，以讓駕駛者有更多時間來對緊急事故作出反應。在最緊急的情況下，所能容忍的傳輸延遲是非常低的，例如聯合碰撞避免系統(Cooperative Collision Avoidance) [9-13]，前方車輛可將事故的訊息，直接透過無線媒介的傳遞給後方的車輛，以避免中間車因為視線上阻隔的所帶來的延遲。此訊息可再藉由車輛上無線裝置的轉送，快速的傳遞給更後面的車輛，因此可以免除掉駕使者本身所需反應時間。

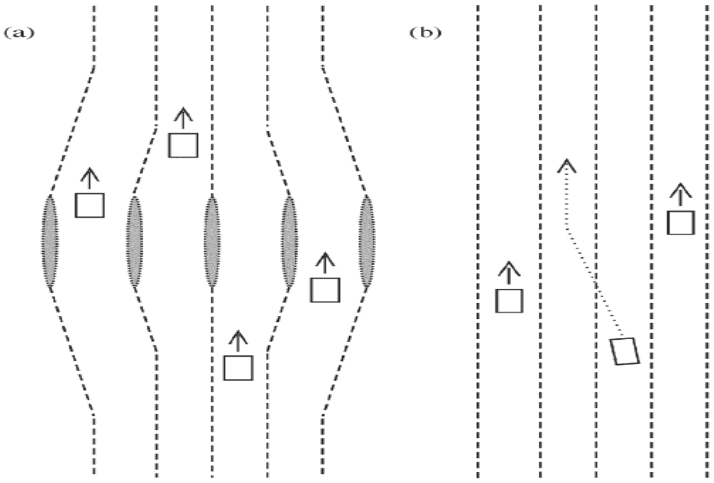
本計畫著重於設計安全服務中所需的緊急訊息廣播機制，這個機制的說明如下。當緊急事件發生時，偵測到事故的車輛(observer vehicle)會產生一個緊急訊息(emergency message)並將些訊息廣播出去。因為這個訊息的內容可能不是對所有車輛都相關，訊息的傳送會限定在一個有限的區域內，稱作風險區(risk zone)。風險區的範圍可能綿延數公里的距離，然而一台車輛的廣播半徑通常只有數百公尺，無法涵蓋整個區域，因此經常需要透過多重跳躍(multi-hop)的方法式進行傳輸。



圖一: 車用隨意網路中的緊急訊息遞送

圖一指出了一個有效的廣播方法:當 observer vehicle 偵測到前方的碰撞事故，立即廣播出一個訊息來告知周邊的車輛，在這同時其中一台接收訊息的車輛會被選作轉送者(forwarder)來進行訊息的轉送，相同的，此轉送者會將訊息廣播出去並選擇下一個轉送者，這樣的動作會一直重覆直到此訊息已傳達到風險區的邊緣。由這個例子我們可以看到，由於訊息都只透過傳送者來廣播，廣播風暴(broadcast storm)問題相對較輕微。然而，如果沒有適當的選者轉送者，將會造成過多的車輛參與轉送，使得資料通道的競爭(channel contention)和資料封包碰撞(packet collision)問題變的嚴重，進而導致較高的延遲時間和傳輸失敗率。另一方面，為了避免資料封包的碰撞，轉送者在接收到訊息後，通常會等待一段隨機的時間才進行轉送，這段等待時間(waiting time)也會增加傳輸的延遲。

為了解決上述問題，本計畫提出了一個以車輛密度為基礎的緊急訊息廣播機制(vehicle-density-based emergency broadcast scheme)，簡稱 VDEB。這個架構主要的概念是透過預估周邊車輛的密度，來減少參與競爭轉送者的數量，並同時降低轉送時所需的等待時間。這個架構也只需要有較少的控制負載(control overhead)，就能達成穩定的運作。



圖二: ETC 自由流動模式 (a) 單車道架構; (b) 多車道架構

此外，高速路電子收費系統(Electronic toll collection, ETC)為目前各國的趨勢[14, 15]。現行的高速公路電子收費模式分為單車道自由流動(Single-lane free-flow, SLFF)與多車道自由流動(Multi-lane free-flow, MLFF)兩種架構[16]。如圖二所示，兩種架構都屬於自由流動模式(free-flow)，允許車輛自由通過收費口，不需設置柵欄迫使車輛停下來。不同點在於MLFF(圖二b) 允許車輛任意切換車道不受閘門的限制，因此車輛可以較高的速度通過收費站，尤其是在車流量高的地區更為明顯。然而 MLFF 設計相對較為複雜，必需有穩定的通訊品質來進行高流量的收費交易。

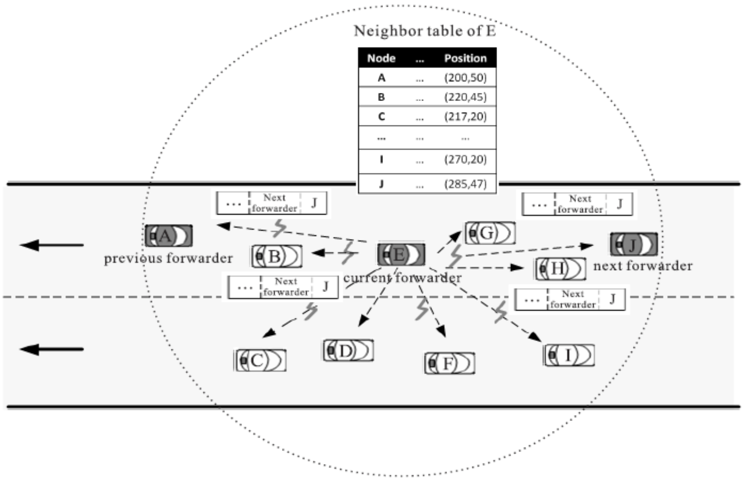
目前 ETC 的通訊主要是以專用短距通信技術(dedicated short range communication, DSRC)。有數種媒介可作為 DSRC 的基礎[17]，如 Infrared、RFID。其中車用環境無線取技術(Wireless access for vehicular environment, WAVE)[18]，提供快速移動車輛一個多頻道(multi-channel)的運作架構，能使車上設備(on-board unit, OBU)與路側設備(roadside unit, RSU)快速的在行車環境中建立車對車(V2V)以及車對路側(V2R)的通訊。有鑑於此，本計畫正著手於 WAVE/DRSC MLFF ETC 系統的設計。我們將利用 WAVE/DRSC 多重通道的特性，提供高車流環境中穩定且快速的交易需求。

二、 研究目的

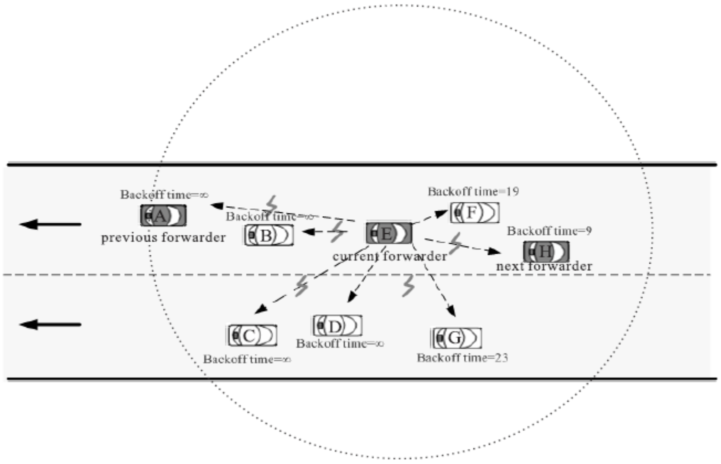
本計畫為總計畫「異質網路環境之行動搜尋關鍵技術」之第一子計畫，主要的目的為提供車用隨意網路之存取控制與連結機制。為了達成這個目標，在第二年的研究中，我們兩項主要的研究: (1)車輛密度為基礎的緊急訊息廣播機制;(2)WAVE/DRSC MLFF 多高速公路電子收費系統。以下分別述之:

1. 車輛密度為基礎的緊急訊息廣播機制

緊急訊息的廣播方法，主要可分為發送端導向(sender-oriented)與接收端導向(receiver-oriented)兩種架構。在發送端導向中[19-24]，傳送端利用正確的鄰居位置來選擇下一個轉送者。由於周邊節點的位置資訊是可取得的，每一個傳送端節點可直接選擇距離自己最遠的鄰居來減少轉送的點。另一方面，由於下一個轉送點已明確地被發送端指定，其它不是轉送點的節點不會參與競爭，因此訊息可在收到後直接地被送出，不需額外的等待時間。如圖三所示，目前的轉送點 E 根據周邊節點的位置，選擇了最遠的點 J 作為下一個轉送點，然後廣播給周圍的點 J 是下一個轉送點。



圖三: 發送端導向緊急訊息廣播架構



圖四: 接收送端導向緊急訊息廣播架構

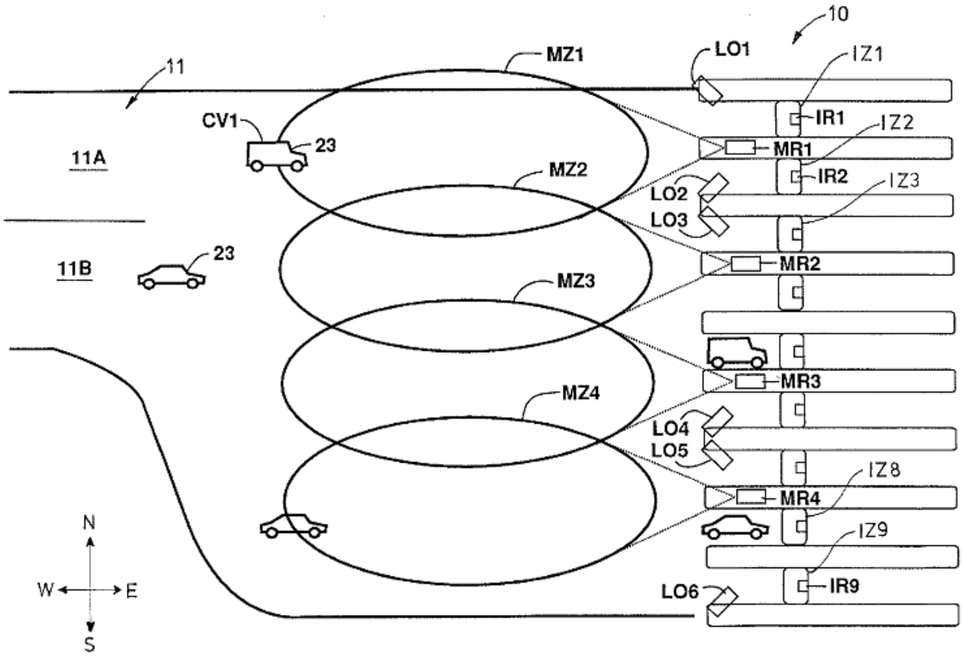
然而，這個架構必需仰賴高頻率且周期的控制訊息來即時地更新位置資訊，才能正確的選擇最遠的轉送點，因此有較高的控制負載(control overhead)，若是資料無法即時更新，更可能會選擇到一個已經脫離涵蓋範圍的車輛作為轉送點，而造成轉送失敗。

而在接收端向導向的架構中[25-28]，轉送點是不會事先由發送端決定好，而是交由接收端自行去競爭傳送權，以選出下一個轉送點。如圖四所示，點 E 是目前的轉送點，首先點 E 會廣播一個訊息給他的鄰居，接下來每一個鄰居會根據接收訊此訊息自行計算一個倒數時間(backoff time)，在點 E 左方的車輛處在訊息傳遞的反方向，因此倒數時間會設為無限大來避免不必要的轉送，而在點 E 右邊的點則會根據相對點 E 的距離以及最大傳輸半徑計算出一個成反比的倒退時間，也就是較遠的點擁有較小的倒退時間，來減少整體轉送的次數。然而在稀疏的網路(sparse network)中，倒退時間可能會有過長的情況，而增加延遲時間。如圖四，點 H 是距離點 E 最遠的車輛，但是這個距離大約只有最大輸半徑的一半，因此儘管右邊以經沒有其它競爭者了，點 H 還是要等待一段較長的時間，才能進行傳送。此外在密集的網路(dense network)中，也可能會有數個節點計算出相近倒退時間的情況，造成較嚴重的干擾問題。

由以上的說明這兩種架構各有其優缺點。有鑑於此，本計畫提出了一個以車輛密度為基礎的緊急訊息廣播機制，這機制結合了兩種架構的優點，可以解決發送端導向架構中較大的控制負載的問題，並同時解決接收端導向架構中嚴重的延遲和干擾問題。

2. WAVE/DRSC MLFF 高速公路電子收費系統

在 ETC 整個系統架構，分成三個模組：扣款模組，執法模組，還有後端模組。在扣款模組方面，必需透過通訊技術完成扣款交易，這部分的技術主要是以專用短距通信技術(dedicated short range communication, DSRC)為主，如 RFID、Infrared 等技術都可作為 DSRC 的媒介，然而各有其缺點，例如目前台灣所使用的 ETC 系統就是使用 Infrared 為主的 DSRC，由於 Infrared 的技術是壟斷的，每年必需支付給國外一筆龐大的權利金。相對的以車用環境無線取技術(Wireless access for vehicular environment, WAVE)為主的 DSRC，由於國際標準已成立，將來將更具有前瞻性。此外 WAVE/DSRC 提供了穩定的多重通道技術，更適合處理 MLFF 這種高車流密度的網路環境。因此我們將以 WAVE/DSRS 作為 MLFF ETC 扣款模組的通訊技術，並設法利用多重通道的特性，提升模組的能力與穩定性。



圖五、出自 US Patent Publication No.:2003/0001755 A1 2003

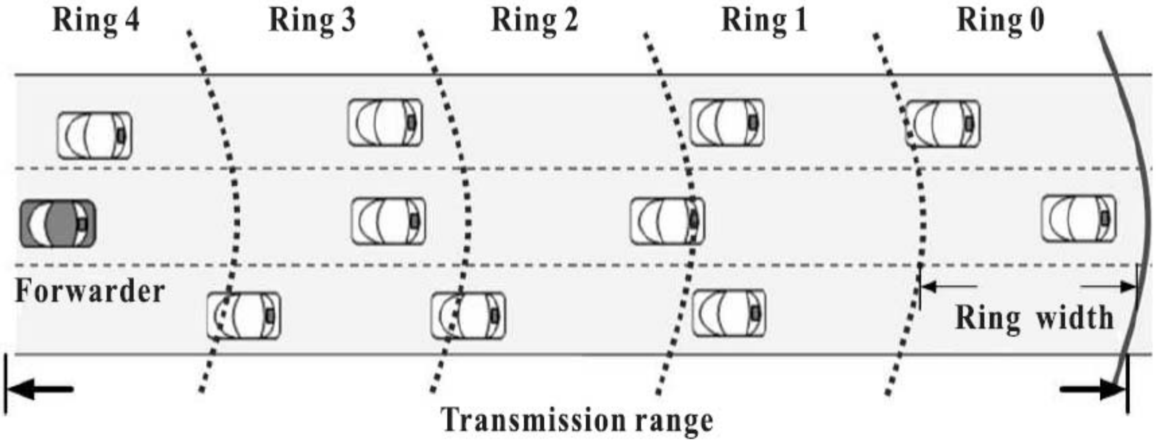
目前國外的 MLFF 大部分都是讓每個車道都處於一個天線的涵蓋範圍，車輛進入這個範圍，執行扣款，這樣的方法是將每個天線都對應到某一個車道，會將接受的訊息跟後端結合去作比對，這樣的方法，車子在發生交易的範圍如果突然切換車道，可能會因為沒有即時更換頻道而導致交易失誤，此外要如何準確的將通道都準確的對應到某個車道，而且相鄰兩個車道也會有交疊的範圍，如圖五 MZ1、MZ2。因此，我們將提出以數個全向式天線涵蓋完整的交易區域的多重通道架構，可以避免追蹤車道所產生的問題。

三、 研究方法

以下針對本子計畫的研究方法及研究成果說明如下：

1. 車輛密度為基礎的緊急訊息廣播機制(VDEB)

車輛密度為基礎的緊急訊息廣播機制(Vehicle-density-based emergency message broadcast, VDEB)採用接收端導向的架構，然而它同時結合了傳送端導向的優點，並設法消除兩種架構的缺點。為了解決接收端導向架構在稀疏網路下倒退時間過長的問題，VDEB將傳輸範圍切成數以送端點為圓心的環狀區帶，兩個環狀區帶所的間隔距離稱作環寬度(ring width)，環寬度是由發送端根據周圍車輛的密度所決定，發送端一旦決定了環寬度，就會將些訊息包含在廣播訊息中，並廣播給周邊的車輛，收到這個訊息的節點則會根據此環寬度，決定自己的倒退時間。如圖六所示，傳送範圍被均分為5個環狀區帶，每一個區帶會被指定一個不同的倒退時間，倒退時間則是隨著環狀區帶編號的增加而增加，因此處在最外圍區帶(ring 0)的車輛擁有最小的倒退時間。如果在ring 0時槽內沒有訊息被成功傳送，在ring 1區帶內的車輛則會進行傳送。相反的，如果任何車輛成功傳送了訊息，其它的車輛則會取消自己的倒退程序。



圖六: VDEB所分割的環狀區帶

如上所述，環寬度是根據傳送端周圍車輛的密度所決定的，因此每一個車輛必維持一個鄰居表格(neighbor list)，以便追縱傳送範圍內車輛的密度。相對於傳送端導向架構，維持車輛密度資訊的要比維持精確的車輛位置要來的容易。此外為了降低資料更新頻率，我們採用如下的車輛位置預測的機制:

$$CurrentPosition = Position + (CurrentTime - Timestamp) \times Velocity$$

也就是目前車輛的位置(*CurrentPosition*)等於之前資料接收時的位置(*Position*)加上這段時間根據車速(*Velocity*)可能產生的位移。換句話說，透過車輛位的預測，每台車輛可以約略估計當前周圍鄰居的實際數量，而不需經常更新車輛位置資訊。

有了估計好的車輛密度，傳送端則可依據此資訊決定最適當的環寬度，決定的方法如下。首先，我們假設每台車輛前後之間的車距是相等的。在這個假設之下，最小及最大的環寬度可以被輕意的決定。如圖七a，最大的環寬度(*MaxRingWidth*)出現在所有車輛都並排地行駛，因此可由下列公式求得

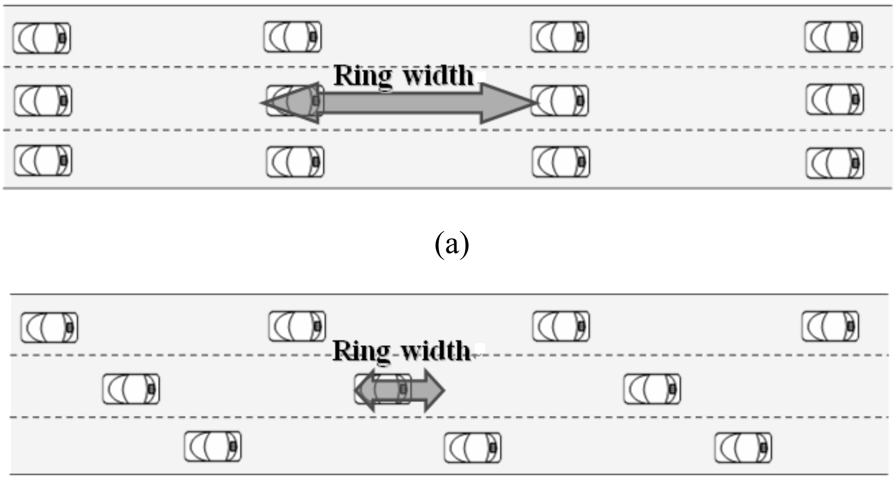
$$MaxRingWidth = \frac{R \times 2 \times l}{N},$$

其中R是傳輸半徑、l是車道數量、N是傳輸半徑內的車輛數量。而最小的環寬度(*MinRingWidth*)則出現在如圖七b的情況，在第二及第三車道的車輛可均分第一車道的車間距離，因此最小的環寬度可以下列公式求得

$$MinRingWidth = \frac{R \times 2}{N}$$

而實際的環寬度(*RingWidth*)，可從最小與最大的區間選取來隨機設定，也就是

$$RingWidth \in [MinRingWidth, MaxRingWidth]$$



(a)

(b)

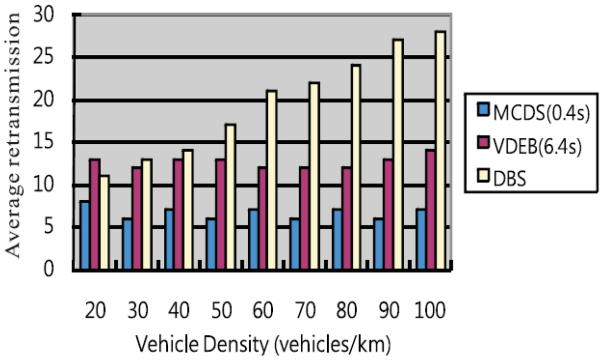
圖七:(a)最小環寬度情境 (b)最大環寬度情境

當收到此環寬度的資訊，接收端可求出所有環狀區帶的數量，並根據本身到傳送端之間的距離，計算出所在的區帶。倒退時間(*BackoffTime*)則是以與區帶編號(*RingNumber*)為等比求得，也就是如下公式

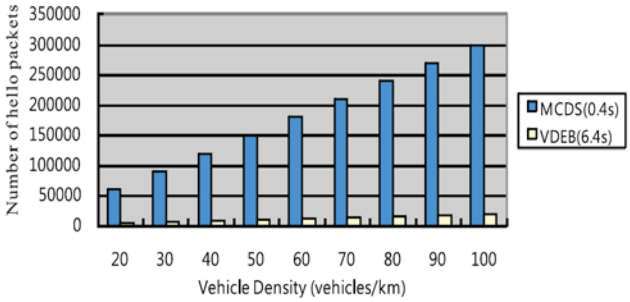
$$BackoffTime = SlotTime \times RingNumber$$

為了驗証我們的設計，我們使用ns2 simulator比較VDEB與MCDS和DBS。MCDS[22-24]是傳送端導向的作法，每輛車使用周期的控制封包來取得最遠鄰居的位置資訊，而DBS[25]是接收端導向的作法，每輛接收到訊息的車輛會根據離傳送瑞的距離，算出自己的倒退時間來進行競爭。圖八顯示這三種作法的平均傳送次數，可看到，由於MCDS總是以最遠的鄰居來傳送，傳送次數是最少的，相反的MCDS有較多的傳送次數，因為有較多的車輛會型成轉送點，而VDEB則是介於中間。但是如圖九所示，VDEB所需的控制訊息是最少的，

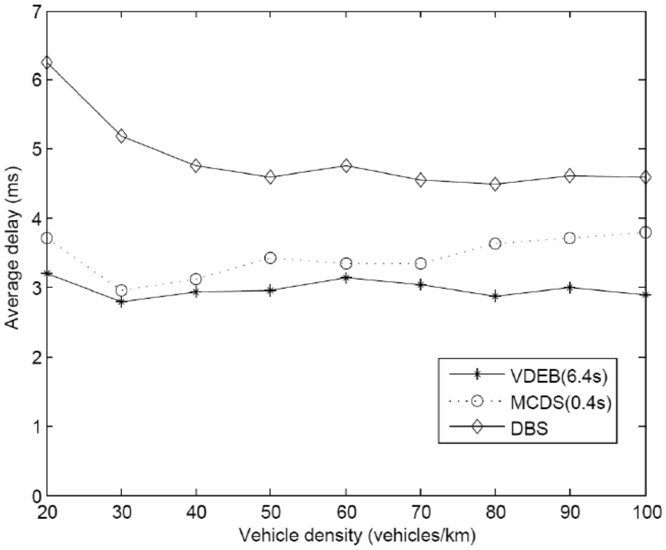
這是因為維持車輛密度資訊所需的更新頻率要比維持精確車輛位置資訊要來的低很多（在我們的實驗裡，分別是6.4s與0.4s）。因此由如圖十，我們可看到VBED整體的平均延遲時間是最低。



圖八:平均傳送次數



圖九:控制封包數量

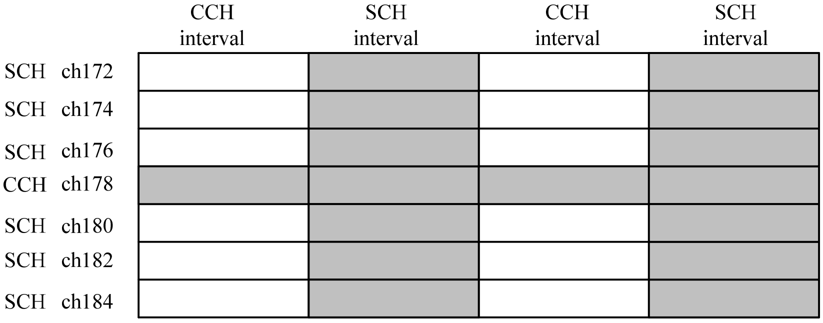


圖十:平均延遲時間

2. WAVE/DRSC MLFF 高速公路電子收費系統

美國 FCC 在 5.8GHz 的頻帶上分配了 75MHZ 的頻寬作法 WAVE 的通訊。如圖十一所示，IEEE 802.11p [29]則將此頻寬分割為七個相等頻寬通道(10MHz)，包含一個控制通道(control channel, CCH)和六個服務通道(service channels, SCHs)，分是給安全與非安全應用使用。IEEE 1609 [30]將頻帶切分為 CCH 區間和 SCH 區間兩個時間間隔，所有的車輛必需在 CCH interval 切換到 CCH 來交換安全訊息，而且 SCH 區間則可切換到不同的 SCH 收送非安全訊息。

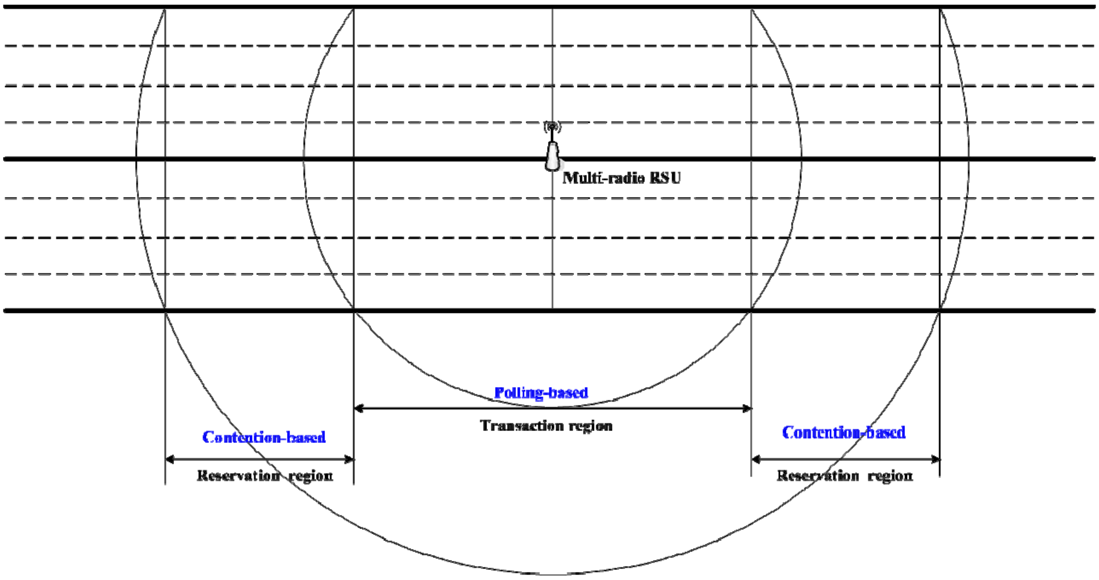
由圖十一，我們可看到在 IEEE 802.11p/1609 標準中，CCH 區間時段下的 SCHs 是閒置的，這是因為現在的車用無線通訊裝置，基於成本的考量，大部分只使用單一的天線(single-radio)，因此無法同時利用 CCH 和 SCHs 的頻寬。然而相對於一般車輛，ETC 收費站屬於大型公有建設，較無成本的限制，因此我們所提出的 ETC 架構，主要是利用具有多重天線(multi-radio)的 RSU 作為收費站的通訊裝置，以利用 CCH 區間時段下的 SCHs 頻寬作為 ETC 交易使用，這樣的好處是可以不被現有的其它 WAVE 服務所影響。多重天線的 RSU 擁有與頻通同等數量的天線，因此可以同時監控所有的通道，並協調不同通道之間的交易，一般的車輛則仍可用單一的天線來降低成本。



	CCH interval	SCH interval	CCH interval	SCH interval
SCH ch172		▨		▨
SCH ch174		▨		▨
SCH ch176		▨		▨
CCH ch178	▨	▨	▨	▨
SCH ch180		▨		▨
SCH ch182		▨		▨
SCH ch184		▨		▨

圖十一:Spectrum allocation in IEEE 802.11p and Time-interval division in IEEE1609

為了保證車輛在經過 ETC 收費站時能順利的完成交易，我們將 multi-radio RSU 的傳送範圍切分為登入區(Reservation region)和交易區(transaction region)內外兩個層次(如圖十二)。車輛進入登入區時，以競爭基礎(contention-based)的方式向 RSU 保留一個 SCH，而在進入交易區時，則可以輪詢基礎(polling-based)的方式，在事先保留的 SCH 上跟 RSU 進行交易，以避免其它訊號的干擾。

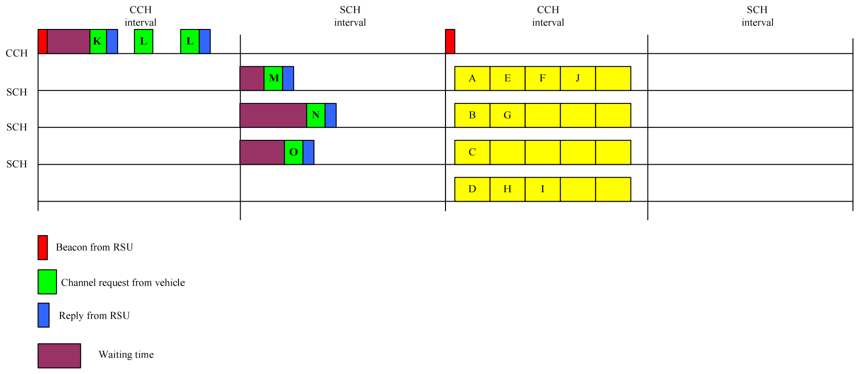


圖十二: 多重天線的 RUS 的區域切分

詳細的運作如圖十三所示，RSU 會在每 CCH 區間的起始發出一個信標訊息(beacon)，告知車輛以進入登錄區並迅速與其進行通道預約。所有車輛在入進登錄區前，可維持 IEEE 802.11p/1609 原本的運作，而當接收到信標訊息後，車輛會在一段等待時間(waiting time)後送出通道預約的請求(channel request)訊息給 RUS，並且等待 RSU 的回覆(channel reply)，上述的競爭動作會持續，直到成功預約一個 SCH 或是車輛駛離登錄區。

等待時間可依據車輛至 RSU 的距離來指定，與 RSU 愈近的車輛將會被指定愈短的等待時間，其目地是為了讓快要進入交易區的車輛，有較高的優先權預約成功。而頻道要求除了可以在 CCH 區間在 CCH 上傳送，由於 RSU 在每個 SCH 上都有天線，車輛也可在 SCH 區間切換到不同的 SCH 頻道要求，以減輕單一控制通道的擁塞情況。

每一個 SCH 可再分割成數個時槽(time slot)，一個時槽必需有足夠的時間讓一台車輛完 ETC 交易。RSU 則會根據車輛預估進入交易區的時間來，指定 SCH 和時槽，最快進入交易區的車輛將會被指定最先有空時槽的 SCH。進入的時間可根據頻道要求中夾帶的車輛位置可速度來預估。



圖十三: Multi-radio RUS 運作法式

當車輛進入到交易區，則會停止一切在 CCH 區間時的傳送，直到收到 RSU 的輪詢要求，才會與 RSU 在預約好的 SCH 上進行交易。一旦車輛完成交易或者駛離交易區，預約的 SCH 會再度被釋放出來，以供後面的車輛使用。除此之外，由於車輛進入到交易區後，會在 CCH 區間切換到不同的 SCH，因此 RSU 必需負責收集這段時間在 CCH 上的訊息，並在 CCH 區間結束前彙整給所有在交易區內的車輛。

總體而言，利用上述的流程，交易的負載可分散至不同的服務通道，避免單一控制通道的擁塞問題。區分登入區與交易區的架構，更可確保車輛在通過入收費站時，不會被其它的傳輸所干擾，以提升系統的可靠度。此外車輛在進行 ETC 交易的同時，仍可透過多重天線的 RSU 的協助，來保證其它安全訊息的接收。因此我們預計這個架構，將可高度整合於未來的車用網路環境。

四、 本子計畫第三年研究目標

本子計畫的主要研究目標，在於發展VANET網路之存取控制協定及連結機制。在第一年的研究中，我們已針對安全應用中重要的聯合碰撞避免(Cooperative collision avoidance)應用，設計了以功率控制為基礎的廣播機制。這個機制是以接收端為導向的架構，因此會有等待時間過長的問題，而且僅適用於特定的應用情境。因此，在第二年的研究中，我們提出了車輛密度為基礎的緊急訊息廣播架構(Vehicle-density-based emergency message broadcast)，這個架構結合接收端導向以及傳送端導向兩種架構的優點，並適用於更廣泛的安全應用。此外我們以WAVE/DRSC為基礎，提出多重通道(multi-channel)架構的MLFF ETC系統。

在達成前兩年的目標後，我們已具備安全應用傳輸與以多重通道的關鍵技術。因此，在三第年的研究中，我們將強調安全應用與多重通道架構的整合問題。首先，我們會持續Multi-channel MLFF ETC的研究，在現有的架構下設計細部的流程，進一步提升穩定度與效能，並進行開發與實測的工作。接下來，我們會將此multi-channel的架構整合到其它的安全應用上。例如利用固定於路邊的multi-radio RUS，來提升單一熱區(hot spot)內傳輸品質，或是利用可裝載multi-radio的車輛(如公車、遊覽車)，來動態的提升整個路段的多重轉送(multi-hop relaying)能力。最後，我們所提出的成本將會透過總計畫與其它子計畫進行整合。

五、 計畫結果

本年度的計畫的研究成果除了上述的成果外，量化的成果包括 1 篇期刊論文，已被 *IEEE Communications Letters* 接受，以及 2 篇會議論文，分別在 *I-SPAN* 2009 與 *Mobile Computing Workshop* 2010 會議發表，並培育了 4 位碩士生。

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七、附錄

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An Upper Bound of the Throughput for Multi-Radio Wireless Mesh Networks[‡]

Rong-Hong Jan,[*] Shu-Ying Huang[*] and Chu-Fu Wang[†]

Abstract – This paper focuses on how to determine an upper bound of maximum throughput from mesh clients to the Internet (or from the Internet to mesh clients) for multi-radio Wireless Mesh Networks (WMNs) under an interference-free assumption. In the case of the number of channels for assignment being high enough in a multi-radio WMN to meet the interference-free assumption, then the resulting solution can provide the basis for channel assignment and routing to achieve optimal throughput.

Index Terms - Multi-radio wireless mesh networks, Maximum flow problem, Throughput.

I. INTRODUCTION

Multi-radio WMNs are the most promising networking technology recently to extend last-mile broadband Internet access. Due to the fact that a multi-radio WMN contains no wired infrastructure within its serving field, it has a low cost of deployment and maintenance. It is therefore attractive to several wireless network applications, e.g., wireless last mile access of ISPs, broadband home networking, community and neighborhood networks, enterprise networking, building automation, and so on [1]. A multi-radio WMN consists of mesh routers and mesh clients where mesh routers have minimal mobility and form the wireless backbone through wireless links. Other than their routing functionality, mesh routers provide additional functions to support mesh networking. With access point functionality, mesh routers can provide network access for mesh clients within their coverage area. With gateway functionality, mesh routers can connect to the wired Internet. Mesh routers can thus be classified into three types, i.e., pure routers, mesh gateways, and mesh APs (see Fig. 1(a)). Each mesh router is equipped with multiple radio interfaces for effective use of available orthogonal channels. Thus, they can reduce wireless interference and increase network throughput [2]. Two of the most challenging research issues in multi-radio WMNs are the channel assignment and the routing problems, which are usually coupled together to maximize network throughput. The channel assignment problem determines the connectivity between nodes, thus the network topology of the WMN is then determined. Based on the resulting network topology, routing decisions can also be made. However, in order to achieve better results, these two optimization problems should be considered jointly, not sequentially [3]. Unfortunately, the joint problem of finding optimal throughput is NP-hard [4].

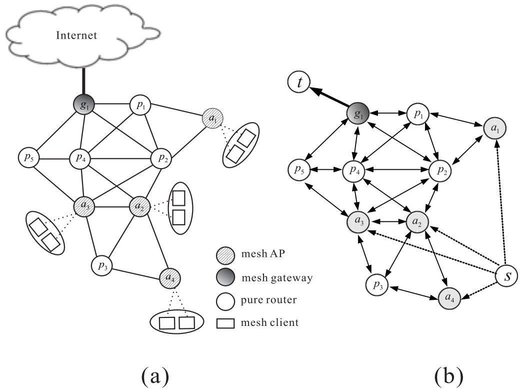

Figure 1. An example for illustrating the problem formulation in multi-radio WMNs.

In this paper, we want to find an upper bound of the throughput for multi-radio WMNs. More precisely, our problem is that, given the deployment of mesh routers and the number of radio interfaces of each mesh router, we want to find the maximum flow from mesh clients to the wired Internet or from the wired Internet to the mesh clients under an interference-free assumption. Since these two cases are symmetric, we only consider the previous case in this paper.

II. PROBLEM DEFINITION

The sets of the pure routers, the mesh gateways and the mesh APs are denoted as V_P, V_G, and V_A, respectively. The network model for finding the maximum throughput from mesh clients to the wired Internet in the multi-radio WMN under an interference-free assumption can be modeled as a directed graph $G = (V, E)$, called the *communication graph*, where V is a set of nodes containing all mesh routers plus a source s and a sink t; that is $V = V_P \cup V_G \cup V_A \cup \{s, t\}$. The source s represents all mesh clients, and the sink t represents the wired Internet. Given any two mesh routers, if the distance between them is less than the transmission radius (we assume that all interfaces have identical transmission radii), there are two directed edges with opposite directions between them. We add an edge from s to every mesh AP and also add an edge from every

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mesh gateway to t (the corresponding communication graph of Fig. 1(a) is shown in Fig. 1(b)). Now, we will formulate the maximum throughput problem of a multi-radio WMN as a network flow-like problem, called the *Augmenting Network Flow Problem* (ANFP) in communication graph G.

Let R_i^B be the number of backhaul interfaces equipped in mesh router i for backbone communication, R_i^C be the number of client interfaces of mesh AP i, c_w be the capacity of the wired link and C be the channel capacity. Thus, the maximum capacity of mesh router (mesh AP) i is equal to $R_i^B \times C$ ($R_i^C \times C$), respectively. The edge capacity c_{ij} for each edge $(i,j) \in E$ can then be set as follows:

$$c_{ij} = \begin{cases} min\{R_i^B, R_j^B\} \times C, & \text{if } i, j \in V - \{s,t\} \\ R_j^C \times C, & \text{if } i = s, \text{ and } j \in V - \{s,t\} \\ c_w, & \text{if } i \in V - \{s,t\} \text{ and } j = t, \end{cases} \tag{1}$$

The flow on G must satisfy two types of basic constraints, i.e., the edge capacity constraint and the node capacity constraint. Let x_{ij} denote the flow on edge (i,j). The edge capacity constraint ensures that the flow on each link cannot exceeded the capacity of the edge and the property of flow conservation. For the node capacity constraint on each mesh router, the sum of incoming flows and the sum of outgoing flows must not exceed its capacity, i.e., its backhaul interfaces multiplied by channel capacity. Therefore, our problem ANFP can be mathematically formulated as follows:

Maximize f
Subject to

$$\sum_{j\in V} x_{ij} - \sum_{k\in V} x_{ki} = \begin{cases} f, & \text{if } i = s \\ 0, & \text{if } i \in V - \{s,t\} \\ -f, & \text{if } i = t \end{cases}, \forall i \in V \tag{2}$$

$$0 \le x_{ij} \le c_{ij}, \forall i, j \in V \tag{3}$$

$$\sum_{k\in V} x_{ki} + \sum_{j\in V} x_{ij} \le R_i^B \times C, \forall i \in V_P \tag{4}$$

$$\sum_{k\in V} x_{ki} + \sum_{j\in V-\{t\}} x_{ij} \le R_i^B \times C, \forall i \in V_G \tag{5}$$

$$\sum_{k\in V-\{s\}} x_{ki} + \sum_{j\in V} x_{ij} \le R_i^B \times C, \forall i \in V_A \tag{6}$$

III. PROBLEM TRANSFORMATION

In this section, we present how to transform the problem ANFP into a maximum flow problem. Comparing problem ANFP to the maximum flow problem, problem ANFP has additional node capacity constraints (4)-(6). Our approach is to transform each of the constraints (4)-(6) into a set of flow conservation constraints and edge capacity constraints using node splitting on sets V_P, V_G, and V_A, respectively. As shown in Fig. 2(a), we split each pure router node $i \in V_P$ into two connecting nodes i_{in} and i_{out}. Node i_{in} has an edge entering it for every edge entering i, while node i_{out} has an edge leaving it for every edge leaving i. We call the resulting graph $G'_P = (V'_P, E'_P)$ an *augmenting communication graph* with pure router nodes splitting. The constraint (4) in ANFP can be rewritten as follows:

$$\begin{array}{ll} & \sum_{k\in V} x_{ki} + \sum_{j\in V} x_{ij} \le R_i^B \times C, \forall i \in V_P \\ \Rightarrow & \sum_{k\in V} x_{ki} + \sum_{k\in V} x_{ki} \le R_i^B \times C, \forall i \in V_P \\ & \text{(by constraint (2))} \\ \Rightarrow & \sum_{k\in V} x_{ki} \le (R_i^B \times C)/2, \forall i \in V_P \end{array} \tag{7}$$

Let flow $x'_{i_{in}i_{out}}$ on edge $(i_{in}, i_{out}) \in E'_P$ be $\sum_{k\in V} x_{ki}$. Inequation (7) can be rewritten as $x'_{i_{in}i_{out}} \le (R_i^B \times C)/2, \forall i \in V_P$ (an edge capacity constraint). The flow $x'_{i_{in}i_{out}}$ can be rewritten as $x'_{i_{in}i_{out}} - \sum_{k\in V} x_{ki} = 0$ (a flow conservation constraint). And by constraint (2), the flow $x'_{i_{in}i_{out}}$ can also be rewritten as $\sum_{j\in V} x_{ij} - x'_{i_{in}i_{out}} = 0$ (the flow conservation constraint). Thus, constraint (4) can be replaced by two flow conservation constraints and an edge capacity constraint. If we set capacity of edge $(i_{in}, i_{out}), \forall i \in V_P$ in G'_P to $(R_i^B \times C)/2$ and set the other edges' in G'_P to c_{ij}, then, we have the following lemma.

Lemma 1. A flow meets the constraint (2)-(4) in G of the problem ANFP, which also meets the flow conservation constraints and the edge capacity constraints in G'_P.

Now, we define the *augmenting communication graph* $G'_G = (V'_G, E'_G)$ with gateway router nodes splitting as follows. Each mesh gateway node i in G is split into two connecting nodes i_{in} and i_{out}. The node i_{in} has an edge entering it for every edge entering i. The node i_{out} has an edge leaving it for every edge leaving i (see Fig. 2(b)). The constraint (5) in ANFP can be rewritten as follows:

$$\begin{array}{ll} & \sum_{k\in V} x_{ki} + \sum_{j\in V-\{t\}} x_{ij} \le R_i^B \times C, \forall i \in V_G \\ \Rightarrow & \sum_{j\in V} x_{ij} + (\sum_{j\in V} x_{ij} - x_{it}) \le R_i^B \times C, \forall i \in V_G \\ & \text{(by constraint (2))} \\ \Rightarrow & \sum_{j\in V} x_{ij} \le (R_i^B \times C + x_{it})/2, \forall i \in V_G \end{array} \tag{8}$$

Note that $x_{it} \le min\{c_{it}, R_i^B \times C\}$. Then, inequation (8) can be rewritten as $\sum_{j\in V} x_{ij} \le (R_i^B \times C + min\{c_{it}, R_i^B \times C\})/2, \forall i \in V_G$. Similarly, let flows $x'_{i_{in}i_{out}} = \sum_{k\in V} x_{ki}$ and $x'_{i_{out}t} = x_{it}$. We replace constraint (5) by a capacity constraint $x'_{i_{in}i_{out}} \le (R_i^B \times C + min\{c_{it}, R_i^B \times C\})/2, \forall i \in V_G$ and two flow conservation constraints $\sum_{k\in V} x_{ki} - x'_{i_{in}i_{out}} = 0$ and $x'_{i_{in}i_{out}} - (x'_{i_{out}t} + \sum_{j\in V-\{t\}} x_{ij}) = \sum_{k\in V} x_{ki} - (x_{it} + \sum_{j\in V-\{t\}} x_{ij}) = \sum_{k\in V} x_{ki} - \sum_{j\in V} x_{ij} = 0$. If we set the capacity of the edge $(i_{in}, i_{out}), \forall i \in V_G$ in G'_G to $(R_i^B \times C + min\{c_{it}, R_i^B \times C\})/2$, and set the capacity of the edge (i_{out}, t) to $min\{c_{it}, R_i^B \times C\}$, and set the other edges in G'_G to c_{ij}, then, we have the following lemma.

Lemma 2. A flow meets constraint (2)-(3) and (5) in G of the problem ANFP, which also meets the flow conservation constraints and the edge capacity constraint in G'_G.

Similarly, constraint (6) can be transformed by two flow conservation constraints and a capacity constraint in the *augmenting communication graph* $G'_A = (V'_A, E'_A)$ with mesh AP router nodes splitting (see Fig. 2(c)). If we set the capacity of the edge $(i_{in}, i_{out}), \forall i \in V_A$ in G'_A to $(R_i^B \times C + min\{c_{si}, R_i^B \times C\})/2$, and set the capacity of the edge (s, i_{in}) to $min\{c_{si}, R_i^B \times C\}$, and set the other edges in G'_A to c_{ij}, we have the following lemma.

Lemma 3. A flow meets constraint (2)-(3) and (6) in G of the problem ANFP, which also meets the flow conservation constraints and the edge capacity constraint in G'_A.

Let $G'_{PGA} = (V'_{PGA}, E'_{PGA})$ be the resulting augmenting communication graph with vertex sets V_P, V_G, and V_A splitting. And let the capacity c'_{ij} of edge (i,j) in G'_{PGA} be the values defined in Lemmas 1-3 (see Fig. 2). Then we have a

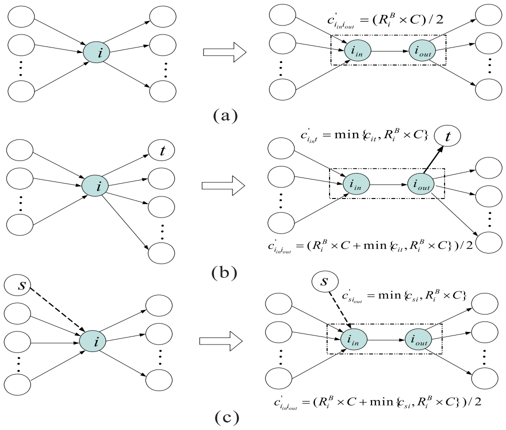


Figure 2. The illustration of nodes splitting.

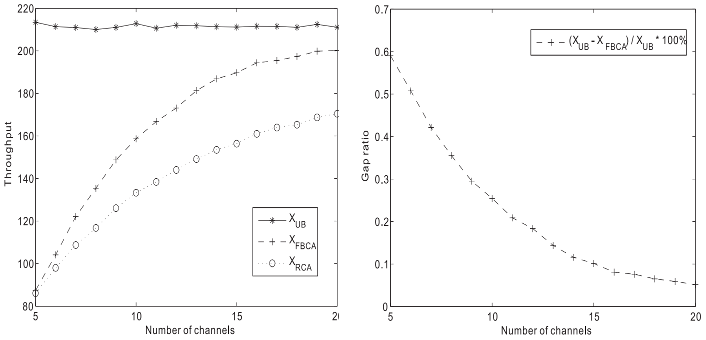
network flow problem on graph G'_{PGA}. By Lemmas 1-3, we have the following theorem.

Theorem 4. The problem ANFP in graph G can be transformed into the network flow problem in G'_{PGA}.

IV. ANALYSIS

Now, we give the time complexity analysis for solving the network flow problem in G'_{PGA}. Note that the cost of splitting every mesh router i into i_{in} and i_{out}, to obtain V'_{PGA} is $O(|V|)$. The cost of adding a new edge (i_{in}, i_{out}) and assigning its capacity, repeated $|V|$ times, is also $O(|V|)$. The total cost of this construction is therefore $O(|V|)$. Note that $|V'_{PGA}|) = 2|V|$ and $|E'_{PGA}| = |E| + |V|$, if we apply the Edmonds-Karp algorithm to the graph G'_{PGA}. Hence, the total cost of finding a maximum flow in the original graph $G = (V, E)$ is $O(|V|) + O(|V'_{PGA}||E'_{PGA}|^2) = O(2|V|(|E| + |V|)^2)$.

On the other hand, we have conducted simulations to demonstrate how tight the proposed throughput upper bound is. In the simulations, we observe the gap between the throughput upper bound (X_{UB}) and the solution values (the lower bounds) found by two heuristic channel assignment algorithms, the flow-based channel assignment (FBCA) algorithm and the random channel assignment (RCA) algorithm, respectively. The FBCA algorithm uses a greedy approach to assign channels. At first, it ignores the channel interference constraint and performs the maximum-flow algorithm on the communication graph G to determine the possible total incoming load of each node. Then, it assigns the remaining available channels to the interfaces of nodes one by one in non-increasing order of the load value of each node. For the RCA algorithm, the channels are randomly assigned to each node's interfaces. The solution values found by the FBCA algorithm and the RCA algorithm are denoted by X_{FBCA} and X_{RCA}, respectively. In the simulations, we consider an 8×8 grid network. For each topology, we choose 30 mesh APs and 6 mesh gateways randomly. The remaining nodes are pure routers. Each pure router (mesh gateway) is equipped with 2 (5, respectively) backhaul interfaces. Each mesh AP is equipped with 2 backhaul interfaces and 1 client interface. The capacity of each channel is 10 Mbps and



(a) (b)

Figure 3. Numerical results.

the capacity of the wired link is 100 Mbps. Fig. 3(a) shows the effects of the number of channels on the network throughput. Each data point in Fig. 3(a) is the average over the 1000 topologies. Note that X_{FBCA} and X_{RCA} can serve as the lower bounds of the optimal throughput and X_{FBCA} is better than X_{RCA}. Thus, the optimal throughput is guaranteed to fall between X_{UB} and X_{FBCA}. Fig. 3(b) shows the gap ratios of the value X_{FBCA} to the upper bound X_{UB} where the gap ratio is defined to be $(X_{UB} - X_{FBCA})/X_{UB} \times 100\%$. From Fig. 3(b), we learn that the gap ratio is less than 10% if the number of available channels is greater than 15. This means that our proposed throughput upper bound X_{UB} is close to the optimal throughput if the number of available channels is greater than 15.

V. CONCLUSION

In this paper, given the deployment of mesh routers and the number of radio interfaces of each mesh router, we want to find the maximum flow from mesh clients to the wired Internet under an interference-free assumption. We define the maximum throughput of the problem as an upper bound of the throughput for the given wireless mesh network. The proposed problem is transformed into a maximum flow problem, and then the problem can be solved by existing maximum flow algorithms. Therefore, an upper bound of the throughput for the given wireless mesh network can be obtained in polynomial time.

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A Real-time Traffic Estimation Protocol in VANET

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摘要

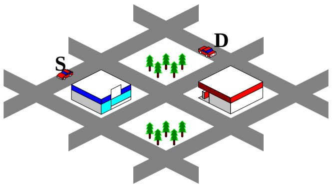
本篇論文針對車用隨意網路(Vehicular Ad Hoc Networks，VANET)，提出了一個精準的即時測量車輛密度的協定，名為即時交通流量估計協定(Real-time Traffic Estimation Protocol，RTEP)。RTEP 以位置導向傳遞(position based forwarding)為基礎，並利用周期性發送的哈囉(hello)訊息將自己的位置告知鄰近點。因此，每輛車可獲得臨近的車輛數並且將路段上的車輛總數加總，再以哈囉訊息將此車流估算值(traffic value)散播在此路段上。我們將預測每一車輛的行車最大速度，並引入安全傳輸距離的觀念，讓網路中具有較高穩定度的無線鏈結點，成為下一個跳躍轉傳點，因此大幅提高了 RTEP 的成功率，並降低資料傳遞量。最後，我們用 NS2 網路模擬器來評估我們的 RTEP 效能，實驗結果顯示在不同的平均車速、車輛密度跟資料流下，RTEP 皆有不錯的準確率。

關鍵詞：Vehicular networks, Vehicle-to-Vehicle, VANET

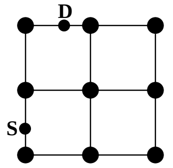
1. 簡介

在歐、美、亞洲已有不少國家佈建了智慧型運輸系統(Intelligent Transport Systems，ITS)，此系統雖然使人們生活水準提升，但現今的智慧型運輸系統還是相當依賴基礎建設的架構，如：路旁的感應裝置、攝影相機…等。智慧型運輸系統的領域很廣，其中 車用隨意網路（Vehicular Ad Hoc Networks，VANET）近來更受到大家的重視，不少學者紛紛投入此一研究。因為此類系統，除了有路側裝置對車輛(Roadside-to-Vehicle，R2V)的網路架構外，還具備有車輛對車輛(Vehicle-to-Vehicle，V2V)的溝通模式，如此將可減少基礎建設網路的使用。再者，利用此 V2V 的架構，即使在缺少基礎建設的鄉村地區，也能保有基本車間網路可供車輛使用。假若我們可以利用車間網路來傳送訊息，把安全警告封包運用在車禍碰撞警告、紅燈減速提醒等應用上，將更能保障我們的生命安全。目前已有研究提出數種可能的網路架構來連結車間的通訊：如直接無線車輛對車輛間的隨意網路；或是僅一步跳躍後連上有線的後端網路；最後是混合式的架構，混合使用前二者通訊模式的網路架構。在混合式架構裡，車間通訊可不依靠基礎建設的架構，但可擁有基礎建設架構的優點，讓車輛可在某些情況下傳送資訊，進而提升整個網路的效能。

在 MANET 中的繞徑是把通訊儀器當成節點，兩個設備若位在彼此的傳輸範圍內，則存在一條的連線；而道路導向繞徑是以道路為基本構成的繞徑方法，此繞徑把街道圖(圖 1(a))轉換成一個道路網路拓撲；其中交叉路口被當成節點，而兩個路口所夾的道路成為連線，如圖 1(b)所示。但由於 VANET 中車輛快速移動的特性，使得一些在 MANET 上之著名繞徑方法[2]-[4]無法直接應用在 VANET 的環境中。因此，各種針對 VANET 環境之繞徑方法紛紛被提出，其中利用道路車輛密度來做路徑選擇的道路導向繞徑(road-based routing)便是主要的方式之一。



(a) 格子狀街道圖



(b) 道路網路拓樸

圖 1：街道圖轉網路拓撲示意圖

一個繞徑協定的好壞，可由下列幾個方向去評斷：封包傳遞率之高低、點對點的延遲時間長短或繞徑協定的控制負載程度等。在 VANET 中，若想要提高封包傳遞率、縮短點對點的延遲時間、減少繞徑協定的負載，則車輛密度是個重要關鍵。一般來說，車輛密度愈高的道路，可供選擇的封包傳遞路線也愈多，繞徑協定就是要選擇此類的路線來進行封包的傳遞，因此，道路導向的繞徑協定會將車輛

密度較大的邊的權重值設定較高，在做繞徑路徑選取時被選擇成為路徑的機率將會比較大。所以，車輛密度估計的精準度將會影響整個繞徑協定的效能。因此，在本篇論文裡，如何得到即時的車輛密度將是我們關注的焦點，我們提出了一個即時交通流量估計協定(Real-time Traffic Estimation Protocol，RTEP)。實驗模擬結果顯示 RTEP 有不錯的準確度。RETP 可用於 VANET 之各種應用中，並能改善延遲太久或只使用歷史車流資料而造成誤差過大的缺陷。

本論文架構如下：在第二章我們將介紹 VANET 背景知識跟相關研究。而 RTEP 方法則將在第三章做詳細的介紹。第四章將描述 RTEP 準確度的模擬與探討。最後是本論文的結論。

2. 相關背景與研究

2.1. 車用隨意網路簡介

車用隨意網路(Vehicular Ad Hoc Networks，VANET)是由車輛(vehicles)組織成無線隨意網路(ad hoc network)型態的一種網路。參與 VANET 的車輛必須裝置通訊設備，使其有成為網路節點的能力。此通訊設備具有基本的計算能力，使車輛能夠自我判斷封包的行為模式；並具有傳遞資料與交換資料等用途。

在本論文裡，V2V 的架構是主要討論範圍，V2V 以車輛為節點，當車輛在道路上行走，若車輛彼此在通訊範圍內，且有一條可利用的連線，多輛車之間將形成一個網路，並可以多跳躍傳送訊息，這就形成一個 VANET。因此，VANET 其實就是無線隨意網路的一個特例。在文獻[1]裡提到無線隨意網路的許多特色，但在 VANET 有幾點特性不同於無線隨意網路：(1)VANET 移動更加快速，但速度大致是可預測的；(2) VANET 的拓撲是極動態的，由於車輛的高速移動性，車輛間彼此的連結狀況也會變動的很快；(3) VANET 節點的移動是被限制住的，不像無線隨意網路的節點能有隨意方向的移動，車輛只能限制在道路上行駛，正因為這點，我們可以大致預測出車輛在某段時間後的位置；(4)網路規模會大的多，只要有車輛的存在，網路規模就可以無限的延伸；(5) VANET 之間的連線會常斷離，如紅綠燈的阻隔，或者是人為的加減速；(6)車子使用汽油等當作能源，故在 VANET 裡，能量節約將不是主要議題。在文獻[7]裡，作者把 VANET 跟 MANET 作了比較(如表 1)，這些差異顯示出我們要在 VANET 散佈資料會變的比無線隨意網路上更加困難。

表 1：MANET 跟 VANET 的差異處

	MANET	**VANET**
節點數目	通常在 100～1000 之間	沒有明確界限，可能為上百萬輛車輛
移動區域	通常為幾萬平方公尺之內	沒有明確界線，可以大到一個國家的範圍
移動性	低度～中度	高度
節點移動軌跡	隨機方向	大多為單一方向
節點分布	隨機且均勻的	稀疏且分散的

2.2. 車輛密度的計算

在傳統測量車流量的方法，主要是依靠在路旁或公共設施上架設感測裝置，例如：攝影機跟雷達，在[12][13]的方法就是利用此種方式。此類方法的缺點是沒有架設感測裝置的路段，就無法得知其道路的車輛密度，若要每條路都裝上感測裝置將會花費很大的佈建跟維護成本，因此使用上受到了極大的限制。[14]提出了一個減少感測裝置的方法，這篇文章利用中點法可以算出理想的感測裝置個數，進而降低一些成本的花費。

以往都是利用集中式的方式去計算並散播車輛密度，除了成本的因素，資訊散播的延遲也是一大問題。車輛密度由路旁裝置偵測出以後，路旁裝置再往後端伺服器傳送資訊，後端伺服器整合計算所有路段的車輛密度，然後再散佈回各路段上，這過程有著數十分鐘的延遲，將造成精準度的誤差，若只是想知道此路段的擁塞程度，本方法尚可使用，但若想用來做 VANET 上的應用，則即時性遠遠不足。因此，利用車輛間的直接通訊來計算車輛密度，漸漸地被許多學者所重視，使用 VANET 的無線網路架構，不只能降低基礎建設的成本其即時性也可獲得大大的改善。因此，與對向車道的車輛做資訊的交換，便可得知其他路段的擁塞程度[8]，進而事先做行車路線的規劃。這種方式是交換在某時間範圍內在別條道路上的行駛時間，並跟路段長度和運算出來的值做比較，就可大略得知此路段是否正在塞車。而不選擇跟同向車做資訊交換，主要是因為同向車輛所擁有的資訊相似度較高，因此可降低整個車間網路的封包負載程度。

在文獻[9][10][11]是利用跟周圍的車輛做直接溝通，進而求出路段上的車輛密度的方法。其中，文獻[9]的主要想法是，若在少部分的車輛上裝置可偵測車輛數的儀器，則偵測出的車輛數除以可偵測的範圍，將可獲得當地的車輛密度，進而散播給周圍的車子，當周圍的車子收到此資訊後與自己已有的數據平均，則可得到此路段的車密度。文獻[10]提出了一個交通資訊的系統，主要是在說明如何把資訊散播出去，以其資訊內容為基礎來做散佈的化簡，在距離很近的兩輛車，我們僅以一筆資料

來代表此兩輛車，這樣就能在一個廣播周期內散播更多的資訊。文獻[11]是把一條道路切成數個區塊，區塊長度是以無線傳輸範圍來決定，計算此 區塊的當地車輛密度則由離區塊中心點最近的車輛負責。透過彼此的溝通，進而求出整條路上的平均車輛密度。

無論如何，上述的方法所獲得的車輛密度準確率都不高；像是用收集當地車輛密度的平均來代表整條路的車輛密度，除非車輛分布很均勻，否則誤差將會很大。而我們所提出的 RTEP 方法將可以避免這類問題。

2.3. 車輛密度與繞徑協定

傳統的 MANET 繞徑，如 AODV[15]跟 DSR[16]，這種繞徑方式是用一連串的節點當作封包傳遞的路徑，這類的繞徑應用在 VANET 上效果會很差，原因如下：VANET 的網路範圍很大，在路徑尋找上有一定難度，另一原因是：車輛的高移動性將造成車輛間的連線極不穩定，因此就算找到了一條路徑，可能在下一秒就會失效。另外以地理位置為基礎的繞徑協定，將會有著比較穩固的連線，如 GPSR[17]繞徑方法，每個點將會利用目的地位置和鄰近點的位置，來決定封包轉送的下一個跳躍點，事先並不會先把傳遞路線規劃好。但此種繞徑的缺點是容易因障礙物的阻隔，而找不到下一個跳躍點，就像是在城市裡沒有出口的巷子，或是被房子等建築物所阻隔。

以道路為基礎的繞徑方法[18][19]改善了前述 GPSR 的問題，有了道路的電子地圖，可以事先規劃封包要沿著哪條路走，進而避免走到死胡同。這類繞徑是用最短路徑的演算法來找尋路徑，但若希望減少封包到達目的地所花的時間，在因沒考慮車輛密度的情況下，很容易選到路上車輛極少且很難找到下一個跳躍點的路徑。在文獻[20]中，作者試著用歷史(像是用月平均或季平均)的車輛密度資料來作為繞徑的選擇依據，然而這還是不足以精準地反應出目前的道路車輛密度。我們所提出的 RTEP 也正是為了解決此問題而設計。

3. 即時交通流量估計協定(RTEP)

即時交通流量估計協定 (RTEP)是利用車輛直接通訊的優點，進而快速且準確的求出車輛密度，當車輛密度愈準確，則 VANET 繞徑的效能也會愈好。圖 2 是一附有車輛密度的電子地圖，圖上的數字是標準化過的車輛密度，其中 *S* 為來源節點，*D* 為目的地節點，較粗的線條即是一條由比較高的車輛密度路段所組成的封包傳遞路線。我們的目的就是想提供各路段車輛密度值即時且準確的估計。

圖 2：有車輛密度的電子地圖

RTEP 是由兩種訊息(哈囉訊息和偵測訊息)、鄰近節點表格、偵測演算法與封包傳送機制等四部份所構成。在本論文中我們將討論單一路段如何採即時分散式的方式算出路段的車流密度。在我們的偵測協定裡，我們假定每輛車子均裝設有車上機(On-Board Unit，OBU)、道路電子地圖和全球衛星定位系統。車上機提供車輛獨立計算且與其他車輛交換資料的能力，是加入 VANET 的基本裝置，道路電子地圖用來提供道路資訊，全球衛星定位系統則是用來做為車子定位的裝置。在本論文裡我們定義車輛密度為每條車道上每公里的車輛數；車流量則定義為每秒通過此路口的車輛數。因此車輛估算值為每公里上的車輛數，亦即：

車輛估算值 ＝ 車輛密度×車道的數目 (1)

3.1. 哈囉訊息與鄰近節點表格

在 VANET 環境裡，因為車子移動性高，自己的位置和鄰近點的鏈結狀況可能會隨時在變動，所以可使用哈囉訊息來隨時更新鄰居節點的位置。在我們的 RTEP 裡，每輛車會定期廣播哈囉訊息。廣播週期(T_0)愈短，則愈能準確告知自己目前的位址給鄰近節點，然而廣播周期小則廣播次數增多，則會增加網路的負擔，反而會影響整個網路接收資料的效能。在本論文中，哈囉訊息主要有三個功用，第一是要能告訴鄰近節點自己的車輛身分代號與移動資訊，如此，車輛才能依據此資訊來進行下一個跳躍點的判斷；第二是當偵測演算法結束後，利用哈囉訊息可以把最新的車輛估算值往回散播進而更新整個路段舊有的車輛估算值；第三是週期性廣播的哈囉訊息可以用來幫助判斷需要開始傳送偵測訊息的時機。

在本論文中，哈囉訊息的組成如圖 3 所示。欄位 Car_ID 是指發送哈囉訊息車輛的身分代號。欄位 Road_ID 是代表此車輛在哪條道路上行駛，此欄位也可以用以避免記錄到別條道路上的車輛資訊。欄位 Position 是指發送哈囉訊息的車輛位置，位置以經度、緯度及高度所構成。而欄位 Velocity 則是用來指出車輛的速率跟方向，當資料在傳遞時，此資訊也是考

慮下一個跳躍點的因素之一。欄位 Traffic_Value 是指最後由 RTEP 所計算出來的車輛估算值。欄位 Timestamp 則是車輛估算值產生的時間。

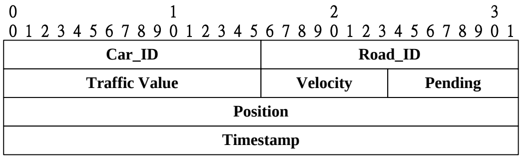


圖 3：哈囉訊息欄位

當車輛接收來自道路上其他車輛所送出的哈囉訊息之後，可以得知其鄰居節點的狀況，因此，每輛車都會有一份鄰近節點表格，其作用是把收到的哈囉訊息裡的內容記錄下來，並儲存到自己的鄰近節點表格裡(如圖 4)，在此表格中若欄位 Valid 為 1，即代表此一記錄所對應到的車輛正處於傳輸範圍之內。由於 VANET 的網路拓撲變化是動態的，因此鄰近節點表格必須做隨時更新的動作，一但發現有某車子已不在通訊範圍內，就必需把此筆資料做移除，則欄位 Valid 主設定為 0。如此便可以得知當地的車輛數。鄰近節點表格的組成如圖 4 所示。欄位 Timestamp 是收到這個資料項目的時間，此欄位之功能是用來更新此筆資料的依據(以秒為單位)，欄位裡的值愈久遠，則此筆記錄的資訊誤差將愈大。因此，我們設定在當某筆記錄的存在時間超過一個門檻值(T_3)時，此時代表已有一段時間沒有收到此輛車的哈囉訊息，判斷其非有效的臨近節點，可能此節點行駛離開了傳送範圍或車上機損壞故障之類的情況，便會將此筆資料刪除。T_3 的設定將會影響鄰近點鏈結狀態的準確性。若 T_3 的值越小，則更新頻率愈大，鄰近節點表格的可靠度會提升，整體的繞徑效能也可獲得改善。

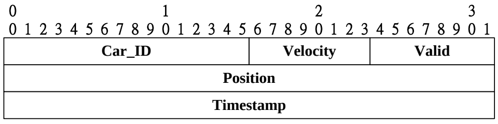


圖 4：鄰近節點表格

3.3. 偵測訊息

偵測訊息是影響 RTEP 效能的主要關鍵，此訊息最後必須總和出整個路段的車輛估算值。與其他論文的計算方法不同之處在於，我們不是利用當地車流密度來做平均，而是算出整個路上的車輛數後，再除以路段長。一般採當地車流密度去做平均的作法，在車輛分布不均勻的道路中，所算出的車輛密度準確率將大受影響，然而我們的 RTEP 卻能改善此問題。圖 5 是偵測訊息的組成欄位。欄位 Destination of intersection 指的是偵測訊息要送往哪個路口，此欄位以座標表示。我們可以利用自己所在的位置、車速與電子地圖作搭配，找出此目的地路口的座標值。欄位 Source 代表一開始發動此一偵測訊息的車輛。欄位 Sum of vehicles 代表截至目前為止，已經累積計算出的車輛總數。當然，若訊息傳到最後的計算終止點，此值將即是此路段的路段車輛總數。而哈囉訊息中的車輛估算值與 Sum of vehicles 裡的路段車輛總數關係如下：

$$\text{車輛估算值} = \frac{\text{路段車輛總數}}{\text{路段長}} \qquad \textbf{(2)}$$

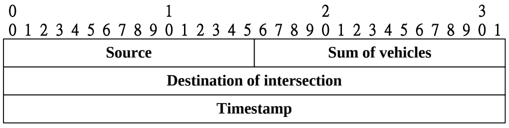


圖 5：偵測訊息欄位架構

偵測訊息被發起傳送後，就必須計算當地的車輛數，並累加於欄位 Sum of vehicles 裡，直到傳送到最後一個計算終止的車輛，最後會得到整段路段上的車輛，再把此值除以路段長並擺放入哈囉訊息的欄位 Traffic_Value 裡。如圖 6 所示，實心的節點為偵測訊息的傳送路徑，為了不讓每個跳躍的當地車輛數出現嚴重的重複計算情形，我們定義而當地車輛數為兩個實心點節點之間的車輛數。

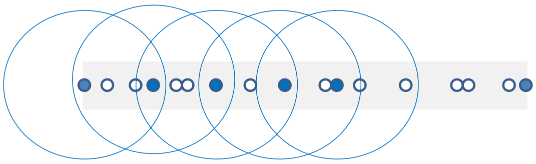


圖 6：當地車輛算法示意圖

3.4. 偵測演算法

車輛一進入新的路段，我們的偵測演算法即會開始運作。此演算法主要由兩個判斷與四個動作所組成，如圖 7 所示。以下將就此些動作即判斷作細部描述。

- 動作一：當車輛進入新路段後，需要等待一段時間(T_1)來接收哈囉訊息，避免哈囉訊息碰。
- 判斷一：在經過了 T_1 秒後，將判斷是否需要傳送偵測訊息。則用下列三點依據來作為判斷依據：
  1) 這條路是否從沒計算過車輛估計值，若都沒算過即開始送偵測訊息。
  2) 先前的偵測訊息是不是傳送失敗了，亦即離現在的時間若已大於 T_2 秒，就開始

傳送偵測訊息。

3) 現有的車輛估計值是否已過期了，我們可用現在時間減去欄位 timestamp 裡的時間是否大於 T_3 秒，來作為是不是過期的判斷。

若上述判斷為是，則將往下進行動作二，否則將結束偵測演算法。如此可降低偵測訊息的傳送量，避免增加網路的負擔。

- 動作二：在開始初始偵測訊息時，需要把前述所等待的 T_1 秒裡有新進的車輛加入計算(圖 8 可看出因等待 T_1 秒而新進來了兩輛車)，因此在傳送偵測訊息給下一個跳躍點前，除了原本的定義外，必需把修正車輛也加入欄位 Sum of vehicles 之中，如此即可減少因等待而造成的誤差。
- 動作三：往目的路口傳遞偵測訊息，並在每個中間跳躍點累計當地車輛數至欄位 Sum of vehicles。
- 判斷二：車輛本身位置離目的路口是否已經小於傳輸半徑，若答案為真，則結束繼續傳遞偵測訊息。否則，重複執行動作三。
- 動作四：算出車輛估算值後，利用哈囉訊息來散播新的 traffic_value 到這條路段上，讓所有車輛更新估算值。

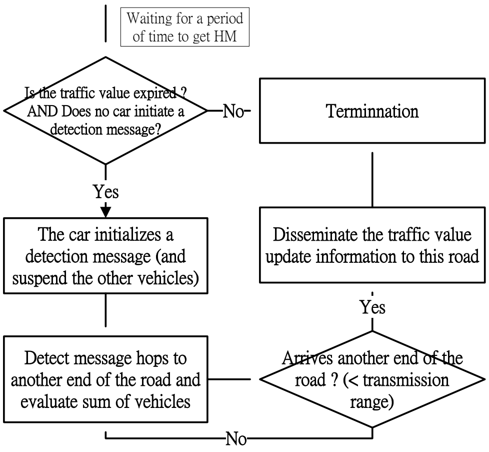


圖 7：偵測演算法流程圖

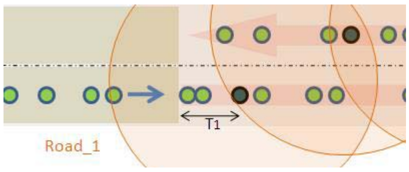


圖 8：偵測演算法初始步驟中
車輛數修正示意圖

3.5. 封包傳送機制

此封包傳送機制是用來說明封包如何被傳遞到目的路口，在我們的 RTEP 裡，是以位置導向傳遞作為我們主要的基礎方法，另外再加上安全傳送距離的判斷機制。其中位置導向傳遞需要知道鄰近點的資訊，而因我們有使用哈囉訊息傳播的方式，每輛車均會廣播哈囉訊息給鄰近的車輛讓他們知道傳送車輛的身分代號、位置、速度等資訊，如此一來，每一個傳送車輛即能知道鄰近車輛的位置。而選擇下一個跳躍點的方式就是選鄰近節點表格裡最接近目的路口的點，所以封包也有可能被傳遞到對向車道去。如圖 9 所示，箭頭為封包的傳遞路徑。由於 RTEP 是一種分散式運作的方法，因此，在資料傳至每個當地跳躍點車輛時，才會決定出下一個跳躍點。

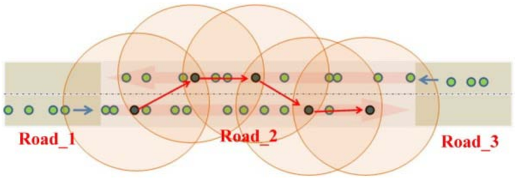


圖 9：封包傳遞路徑圖

由於 VANET 的高移動性、哈囉訊息週期性以及鄰近節點表格更新的頻率等，都會影響鄰近節點位置資訊的準確率，若選太接近傳輸邊界的車輛作為轉傳點，這雖然可減少跳躍數及時間延遲，但卻多了鏈結不穩定性的反效果，導致在決定下一個跳躍點後，卻很快地發生鏈結斷離而找不到此一節點的情況發生，因此封包將會被丟棄，偵測訊息的傳遞率將會因此而下降。在本論文中，我們提出了安全傳送距離 (D)的判斷機制來作為尋找跳躍點的依據，以改進前述遺失之發生可能。本論文定義安全傳輸距離如下：

$$D = R_{\max} - \left(V_{\max} \times \delta\right) \tag{3}$$

其中，D 為安全傳輸距離；$R_{\max}$ 為車輛最大傳輸半徑；$V_{\max}$ 為車輛最大速率；δ 為修正的時間。修正的時間定義如下：

$$\delta = T_{now} - \rho \tag{4}$$

其中 T_{now} 是現在的時間；ρ 為鄰近結點表格裡的 Timestamp 時間戳記。因為我們都是用鄰近節點表格來做傳遞機制，但裡面的位置資訊並非就是現在的分布狀況，所以需要作修正。按上列安全傳輸範圍的定義是以最大的傳輸半徑減去一個危險區塊長度，而危險區塊長度的估計則是用車輛最大速度乘以修正的時間來估算。待安全範圍被估算出來後，我們所以提的 RTEP 則會將超過安全距離的車輛排除使之不會成為下一個跳躍點，如圖 10 所示，原本 A 車的下一個跳躍點是應 C 車，但由於 C 車在安全傳輸範圍以外，故將會改選 B 車成為下一個跳躍點。

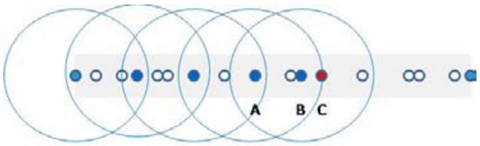


圖 10：安全傳輸範圍示意圖

4. 模擬結果與分析

在本章節我們將展示 RTEP 的效能，藉由車輛密度、車輛速度跟資料流大小的調整來作為模擬探討。

4.1. 封包傳送機制

我們是模擬一條雙向道路來估算實質的效果，如圖 11 所示，模擬的車輛會從此路的兩側路口駛入，並往另一端路口駛去，車輛不會停下或倒退行駛。車輛的速度以正常範圍 8 公尺/秒到 20 公尺/秒之間，換算成時速，大致為每小時 30～70 公里。路口座標指的是路段兩端的正中間，車輛會往此座標作封包傳遞的方向。另外緊鄰著路口中心還會擺置兩台固定的無線儀器(如圖 11 的 A 和 B 兩節點)來負責產生跟接收資料流，在傳輸層我們採用 UDP 來傳送大小為 1000 位元組的封包，並使用固定位元速率來傳遞。詳細參數列於表 2 中。

圖 11：模擬道路圖

表 2：環境參數表

實驗環境	媒介存取控制層	802.11 DCF
	傳輸半徑	250 公尺
	路段長	1 公里
	道路型態	兩線道的雙向道路
RTEP 參數設定	hello 訊息週期(T_0)	0.5 秒
	偵測演算法的等待時間(T_1)	2 秒
	判斷偵測訊息是否成功的等待時間(T_2)	3 秒
	車輛估算值的有效時間(T_3)	5 秒
模擬參數設定	車輛進入間隔	exponential distribution, λ=1, 5, 10, 15, 20 秒
	車輛速度	8～20 公尺/秒
	資料流(CBR)	0, 1, 2, 3, 4, 5 千位元/秒

4.2. 模擬結果

首先，我們希望求得車輛密度的大小對於準確率的影響程度。我們用 5 個 λ 值，分別為 1、5、10、15、20，來表示不同的車密度。其換算關係如方程式(5)所示：

$$\begin{aligned}\text{平均車密度} &= \frac{\text{車輛數}}{\text{路段長}} \\ &= \left(\frac{2\times\text{路段長}}{\lambda\times\text{平均車速}}\right)\Big/\text{路段長} \\ &= \frac{2}{\lambda\times\text{平均車速}}\end{aligned} \tag{5}$$

我們從圖 12 可以看出當車密度改變，但在足夠的車輛數條件底下，準確率還是能夠維持在 90%以上。即使車輛變稀疏(λ = 20)，準確率依舊能有 75%左右。這結果說明了當偵測訊息傳遞率下降時，車輛估算值無法定時更新，因此，只能利用歷史估算值作代替，所以準確率會下降。

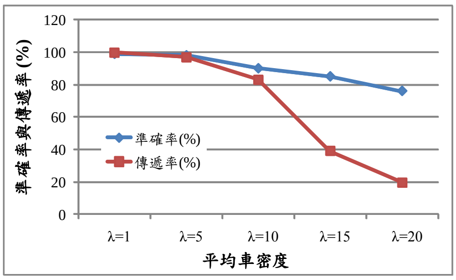


圖 12：平均車密度與準確率和傳遞率關係圖

接下來，在第二個模擬實驗中，我們將探討不同平均車速對於準確率與傳遞率的影響。以 5 種平均車速作模擬，從圖 13 可以看出，當平均車速變快時，準確率會略為下降，但在平均時速為 60～70 公里時，準確率還是能有 97.5%以上。RTEP 是用鄰近節點表格來判斷周圍的節點，所以當平均車速上升，鄰近節點表格所記錄的節點誤差也會變大，導致準確率下滑。另外，我們可從圖 13 發現，平均車速不是影響偵測訊息傳遞率的主要原因。

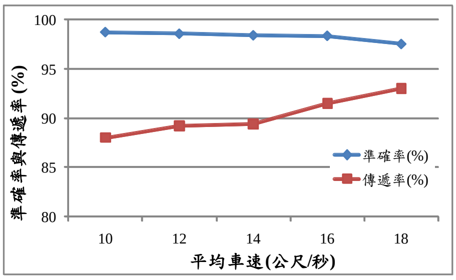
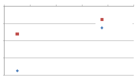


圖 13：平均車速與準確率和傳遞率的關係圖

最後，在第三個模擬實驗中，我們增加資料流到路段上，並觀察其準確率之變化。在模擬道路圖(圖 11)中，我們加入了 CBR 資料流，並從 A 點傳送到 B 點，再探討六種不同的 CBR 對準確率的影響。模擬結果如圖 14 所示，我們可以看出改變了資料流後，我們的 RTEP 效能還是不錯的，依然有 95%以上的準確率。但



是因為資料流變大，使得封包碰撞的機會增加，因此，準確率也將會些微下降，但以平均車密度來說，對其影響並不顯著。

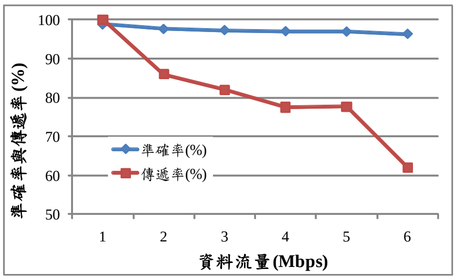


圖 14：資料流與準確率和傳遞率的關係圖

5. 結論

RTEP 的準確率跟即時性能帶來不少好處，除了可應用在 VANET 繞徑外，還能用在動態調整 VANET 之頻道間距上，當車輛密度變大時，RTEP 可以適時提供資訊調整傳送資料的頻道時間，減少有資料未傳完的情形發生；RTEP 更可應用在安全輔助上，例如用估算出的車輛密度來決定緊急封包的散播次數或每個接收者重播的等待時間。從模擬結果可以看出，在不同車輛密度、車輛速度跟資料流的情況下，我們的 RTEP 皆有著不錯的效能，我們所模擬估算出的數值至少都有著 80% ~ 95%以上的準確率；而使用安全範圍的傳送機制，偵測訊息的傳遞率就算在相對速度變大的路況中，也能維持一定的高傳遞率。

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Efficient Broadcast Mechanism for Cooperative Collision Avoidance Using Power Control

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Abstract—**Improving driver's safety has been an active research area in wireless communication. In particular, the vehicle cooperative collision avoidance (CCA) is one of the most important issues in safety applications. A variety of broadcast protocols has been proposed for vehicular network. However, there is only a few of them dedicatedly designed for the CCA system. In this paper, we propose a novel broadcast mechanism for CCA using the power control technique. The power control rule is based on the safe distance between vehicles. Simulation results show that our approach can significantly reduce the delivery delay and avoid car collision.**

Keywords-vehicular networks; power control; cooperative collision avoidance

I. INTRODUCTION

Traffic accidents have been taking thousand of lives each year, exceeding any deadly disease or natural disasters in many countries. Numerous factors, such as bad weather conditions and mechanical failures, may lead to a traffic accident. In particular, the inability of drivers to react in time to emergency events often creates to a series of car crashes, i.e. the chain car collision. As shown in Fig. 1a, three vehicles A, B, and C are driving on a highway platoon. When vehicle A brakes suddenly, vehicle B can start to decelerate after a *driver reaction time*, i.e. the duration when an event is observed and when the driver actually applies the brake, to avoid a collision with A. However, due to the line-of-sight limitation from B, vehicle C may not decelerate until its driver has seen the rear brake light of vehicle B. Studies show [1] that the driver reaction time could range from 0.75 to 1.5s, which means that a trailing vehicle may keep running for a long distance before reacting to an accident ahead. For instance, at a speed of 70 mph, vehicle C may pass through 75 to 150 ft before being decelerated. Consequently, a single emergency event often leads to a string of secondary crashes. Clearly, such an undesirable situation can be substantially avoided or lessened if drivers can be warned earlier.

The Cooperative Collision Avoidance (CCA) is an important class of safety applications in Intelligent Transport Systems (ITS), which aims at offering earlier warning to drivers using vehicle-to-vehicle (V2V) communication [2]. As the example shown in Fig. 1b, once vehicle A confronts an accident, it can directly send out a warning message to C or quickly forward the warning message hop-by-hop to C whenever their distance is beyond the transmission range. As a result, vehicle C can obtain more chance to stop safely, in contrast to counting on the rear brake lights of vehicle B.

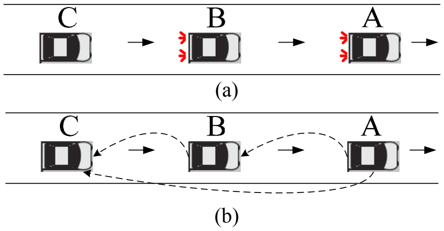

Figure 1. (a) alerted by rear brake lights; (b) alerted by warning messages.

However, due to the severe interference in wireless communication, the deliver delay could be intolerably large, especially when many vehicles have to transmit or forward their warning messages. The delay would result in a longer time to response to the emergency event. The interference problem would become more significant in density traffic roads or multi-lane environments.

In this paper, we present a new broadcast mechanism for the CCA system, named PC-CCA. The PC-CCA employs the power control (PC) technique to reduce the physical interference incurred by delivering warning messages. The power control technique has been considered as an effective way to lessen interference in the wireless environments. By reducing the transmission power of each vehicle, the broadcast radius can be smaller, implying fewer warning messages being forwarded and fewer nodes being interfered.

The rest of this paper is organized as follows. In Section II, we review recent researches related to broadcasting in the Vehicular Ad Hoc Network (VANET) and the CCA system. Section III presents the proposed broadcast mechanism. In Section V, we conduct simulation results. Conclusion is remarked in the last section.

II. RELATED WORK

VANET Broadcast has been studied in several articles, such as in [3, 4, 5, 6, 7]. Xu *et. al.* [3] discussed a vehicle-

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to-vehicle location-based broadcast protocol, where each vehicle generates a warning message at a constant rate. The optimum transmission probability at MAC layer for each message is then identified to reduce the packet collision probability. In [4], the authors propose a multi-hop broadcast protocol based on slot reservation MAC. Considering the scenario that not all vehicles will be equipped with wireless transceivers, forwarding in sparsely connected ad hoc network consisting of highly mobile vehicles is studied in [5]. Motion properties of vehicles are exploited in [6] to help with message relay. In [7]**,** the authors proposed efficient protocols to reduce the amount of messages being forwarded. Compared with MANET broadcast, the above protocols concern the mobility of vehicles to achieve more efficient message forwarding. However, these protocols are not specifically for safety applications (e.g. CCA system), where more emphasis should be paid on the emergency of warming messages.

Several application challenges in the CCA system, such as stringent delay requirement, coexisting abnormal vehicles, and different emergency levels, have been identified in [8]. The authors also designed a protocol comprising congestion control policies, service differentiation mechanism, and methods for emergency warning dissemination. In [9], a broadcast scheme based on a client-server platform is proposed. The rebroadcast probability of each relaying vehicle is changed dynamically according to the number of vehicles insides the transmission zone. The purpose is to avoid relaying redundant warming messages so as to reduce delivery delay. However, this protocol requires each vehicle to acquire information in its two hops range. The control overhead may lead to additional delivery delay.

In order to perform forwarding without prior knowledge about neighbors, Biswas *et. al.* propose two *context-aware* protocols [10], named the naive broadcast (NB) and intelligent broadcast with implicit acknowledgment (I-BIA), for the CCA system. In both protocols, when an emergency event occurs, the source vehicle broadcasts a warming message first, and then a recipient will forward the message only if the direction-of-arrival (DoA) of the message is in front of itself. This mechanism ensures that the warming message will be eventually delivered to all vehicles behind the source vehicle and any vehicle which is not endangered will not forward the message. The I-BIA can further avoid redundant retransmission by setting a waiting time to see if there is any vehicle behind a recipient having received the same message. Similarity, three context-award protocols, named weighted p-persistence broadcasting, slotted 1-persistence broadcasting, and slotted p-persistence broadcasting, are proposed in [11]. In these protocols, vehicles which are farther away from the previous broadcaster will transmit with higher priority (higher probability or earlier time). The purpose is to avoid redundant retransmissions from intermediate vehicles. A similar protocol is presented in [12] for multi-lane highway.

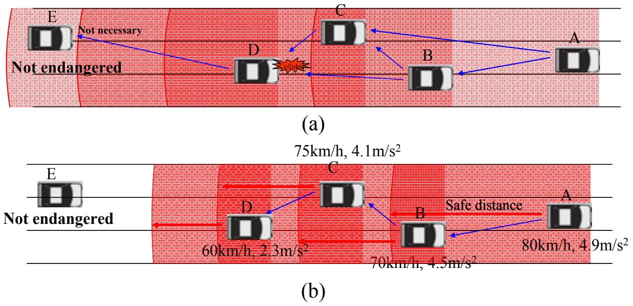

Figure 2. (a) CCA without power control; (b) CCA with power control.

Although the above protocols can make use of directional or other geographic information to reduce overall delay, the local delay may not meet the requirement for each individual vehicle. Consequently, chain car collision may still occur if even the overall delay is low. To solve this problem, a *risk-aware* protocol is presented in [13]. In this protocol, vehicles are classified into several clusters according to the features of their movement. Then, an emergency level is defined for each vehicle based on the order in its cluster. The emergency level reflects the risk of a vehicle to meet an emergency situation in the platoon. The medium access delay of each vehicle is then set as a function of its emergency level to promptly disseminate warning message. However, the order in cluster cannot explicitly reflect the risk, because in real situation many factors, such as intercar space and velocity, are inconsistent from vehicle to vehicle. Besides, the interference is still severe if the physical transmission range is large. To the best of our knowledge, there is no research using power control technique to improve the CCA system.

III. PROPOSED BROADCAT MECHANISM

In this section, we present our broadcast mechanism for the CCA system. First of all, the basic concept is described. After that, we formally model the safe distance between vehicles in vehicular network environment. The power control rule is then summarized in the last part.

A. Basic Concept

The interference may occur when more than one vehicle has to forward the same message within a short period. An example is shown in Fig 2a. Once vehicles B and C received a warning message from A, because they can not be aware of each other, they may forward the message at the same time to the vehicles behind, resulting in a signal collision at vehicle D. The PC-CCA employs the power control technique to physically reduce the interference. As shown in Fig. 2b, by reducing the transmission power, vehicle D can avoid receiving messages simultaneously from both B and C, since only vehicle B receives the message from A at the first place.

The major problem is how to guarantee the delivery to all vehicles which are endangered as long as the transmission power is shrunk. To tackle this problem, our protocol will dynamically adjust the transmission radius based on the *safe distance* between vehicles. As shown in

Fig. 2b, under the given velocities and deceleration rates, we assume that the safe distance between vehicles A and B is *d*, which means that vehicle B is potentially endangered if its distance to A is shorter than *d*. In other words, to avoid being collided by vehicle B, the transmission radius of A should be at least *d*.

Using the power control technique can also avoid transmitting to vehicles which are not endangered. As shown in Fig. 2a, vehicle E is far away from the platoon, i.e. it is out of the safe distance to D. But, if vehicle D always transmits at the maximum transmission power, vehicle E will eventually receive a warning message from D even if it is not endangered. In contrast to Fig. 2b, if vehicle D shrinks its power according to its safe distance to E, vehicle E will never be disturbed and it can avoid relaying useless messages to the vehicles behind any further. In other words, the covered area can be confined into a smaller zone to avoid redundant bandwidth usage.

B. *Modeling Safe Distance*

Before presenting our power control rule, the safe distances between vehicles in vehicular network environments should be carefully modeled. As shown in Fig. 3, three vehicles C_{i+1}, C_i and C_{i-1} are on a highway platoon, where C_{i-1} is in front of C_i and C_{i+1} is behind C_i. Assuming that C_{i-1} is the vehicle confronted an accident, we aim to formulate the safe distance $S_{i,i+1}$ that C_{i+1} should be kept from C_i. The safe distance $S_{i,i+1}$ is then used to model the necessary transmission radius $T_{i,i+1}$ between C_i and C_{i+1} and broadcast radius B_i of C_i. Other symbols used in our model are listed in Table 1. Note that we assume each vehicle can obtain its current position and the UTC time from a Global Positioning System (GPS).

TABLE I. SYMBOLS

Symbols	Meanings
V_i	Velocity of C_i;
D_i	Deceleration rate (regular or emergency deceleration) of C_i;
δ	Average driver reaction time;
L	Car length;
t_i	UTC time when C_i applies emergency braking or receives a warming message from C_{i-1} at network queue;
$\Delta_{i-1,i}$	$\Delta_{i-1,i} = t_i - t_{i-1}$: delivery delay from C_{i-1} to C_i;
$d_{i-1,i}$	Distance between the position of C_i at t_i and the position of C_{i-1} at t_{i-1};
M_i	Moving distance of C_i after t_i;
$S_{i,i+1}$	Safe distance between C_{i+1} and C_i at time t_i;
$T_{i,i+1}$	Transmission radius from C_i to C_{i+1} at time t_i;
B_i	Broadcast radius of C_i at time t_i;

First of all, we need to estimate the moving distance M_i for C_i. The M_i represents the distance that C_i has to run through after C_{i-1} confronted an accident. The model of M_i has three cases, corresponding to the cases of soft brake, medium brake, and hard brake in Fig. 2.

Case 1: C_i stops safely

Case 2: C_i collides with C_{i-1} after (or when) C_{i-1} stopped;

Case 3: C_i collides with C_{i-1} before C_{i-1} stops;

In case 1, C_i applies a hard brake so that it can stop safely before colliding with C_{i-1}. Therefore, after C_i received a warning message from C_{i-1}, it will move at the original velocity V_i during the driver reaction time δ and then move at the decelerated velocity for a period of V_i/D_i before stopping. Let $l(V, D, t)$ stand for the moving distance of a vehicle with velocity V and deceleration rate D during a period of time t. That is,

$$l(V,D,t) = Vt - \frac{D}{2}t^2 \cdot$$

The moving distance of C_i after t_i can be represented as

$$M_i = \delta V_i + l(V_i, D_i, V_i / D_i) = \delta V_i + \frac{V_i^2}{2D_i} \cdot$$

In case 2, since C_i collided with C_{i-1} after (or when) C_{i-1} stopped, its moving distance is depending on the moving distance of the vehicle ahead, i.e. M_{i-1}. Therefore, assuming that the distance between the position of C_i at t_i and the position of C_{i-1} at t_{i-1} is $d_{i-1,i}$, the moving distance of C_i after t_i is the moving distance of C_{i-1} (i.e. M_{i-1}) plus their distance $d_{i-1,i}$. Note that the car length L should be subtracted. That is, the M_i in this case can be given by

$$M_i = d_{i-1,i} + M_{i-1} - L \cdot$$

Case 3 further has three subcases: 3.1, 3.2 and 3.3. Let t_x denote the moving time of C_i before collided and $\chi_{i-1,i}$ temporally denote the moving distance in this case. In subcase 3.1, C_i collides with C_{i-1} before both of them decelerate, which means that

$$\chi_{i-1,i} = t_x V_i,$$

where t_x satisfies that

$$t_x V_i + L = d_{i,i-1} + t_x V_{i-1} \cdot$$

In subcase 3.2, C_i collides with C_{i-1} before C_{i-1} decelerates and after C_{i-1} decelerated, which means that

$$\chi_{i-1,i} = t_x V_i,$$

where t_x satisfies that

$$t_x V_i + L = d_{i,i-1} + \delta V_{i-1} + l(V_{i-1}, D_{i-1}, t_x) - (\delta - \Delta_t) \cdot$$

In subcase 3.3, C_i collides with C_{i-1} after both of them decelerated, which means that

$$\chi_{i-1,i} = \delta V_i + l(V_i, D_i, t_x - \delta),$$

where t_x satisfies that

$$\begin{aligned} &\delta V_i + l(V_i, D_i, t_x - \delta) + L = \\ &d_{i,i-1} + \delta V_{i-1} + l(V_{i-1}, D_{i-1}, t_x - (\delta - \Delta_t)). \end{aligned}$$

Combining the above cases, we have the following function for the moving distance M_i:

$$M_i = \min \left\{ \begin{array}{c} \delta V_i + \dfrac{V_i^2}{2D_i} \\ d_{i-1,i} + M_{i-1} - L, \\ \chi_{i-1,i} \end{array} \right\}$$

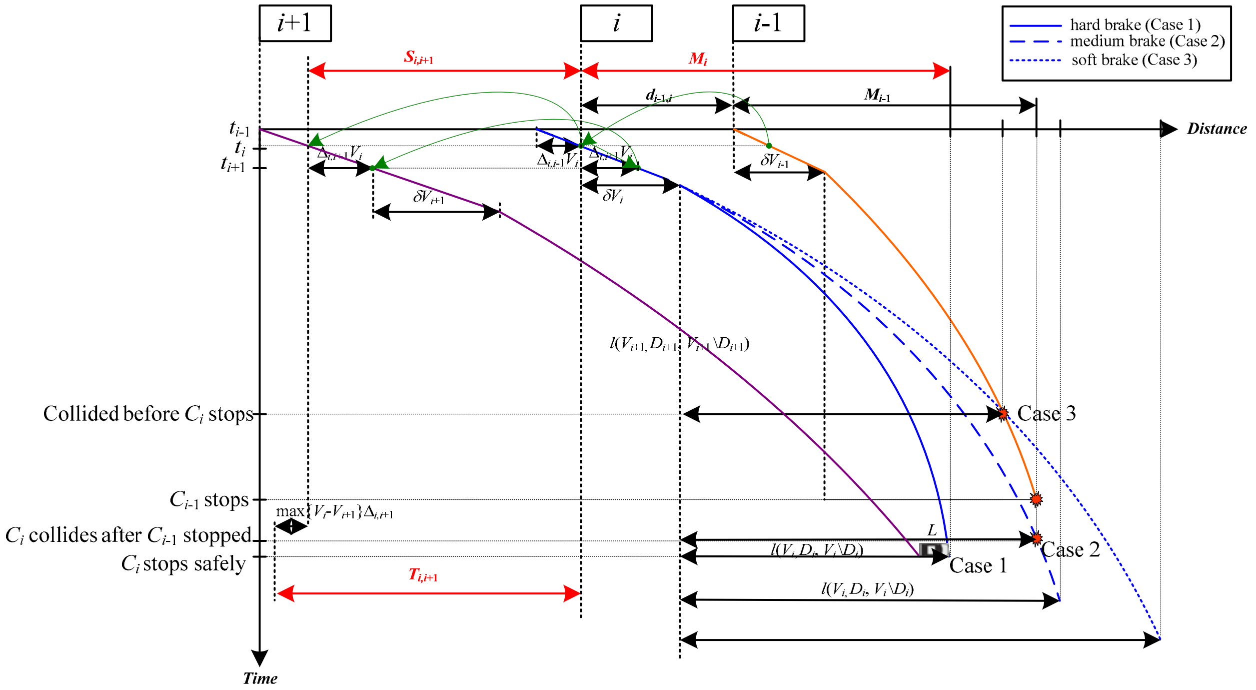

Figure 3. Safe distance and Transmission radius

Based on the moving distance M_i, we can now model the safe distance $S_{i,i+1}$ between C_i and C_{i+1} for C_i. Assuming that C_i can obtain the velocity V_{i+1} and deceleration D_{i+1} of vehicle C_{i+1}, it can know that C_{i+1} will move for a distance of $l(V_{i+1}, D_{i+1}, V_{i+1}/D_{i+1})$ after reacting the warning message from itself. On the other hand, before reacting to the warning message, C_{i+1} has to move for a distance of δV_{i+1} during the driver reaction time. Furthermore, there is a propagation delay $\Delta_{i,i+1}$ so that C_{i+1} has to move at the original velocity V_{i+1} for a distance of $\Delta_{i,i+1}V_{i+1}$. As a result, the safe distance $S_{i,i+1}$ between C_i and C_{i+1} can be modeled as

$$S_{i,i+1} = (\Delta_{i,i+1} + \delta)V_{i+1} + l(V_{i+1}, D_{i+1}, V_{i+1}/D_{i+1}) + L - M_i \,.$$

C. Powr Control Rule

As mentioned above, to send a warning message to C_{i+1}, the transmission radius of C_i should be at least the safe distance $S_{i,i+1}$. Furthermore, because the velocities of C_i and C_{i+1} are not always the same, vehicle C_{i+1} may not receive any message from C_i if their distance was enlarged during the message propagation, i.e. the duration $\Delta_{i,i+1}$. For this reason, the transmission radius of C_i to C_{i+1} should add the enlarged gap. That is,

$$T_{i,i+1} = S_{i,i+1} + \Delta_{i,i+1} \max\{V_i - V_{i+1}, 0\} \,.$$

Now, assume that C_i can be aware of the statuses of all vehicles behind. The broadcast radius of C_i can be set as

$$B_i = (1+\varepsilon)\max_{C_j \in P_i}\left\{\, T_{i,j} \mid d_{i,j} \le T_{i,j} \right\},$$

where P_i is the set of vehicles behind C_i and $\varepsilon \ge 0$ is a factor to cope with the possible wireless channel fading.

However, if the statues of the trailing vehicle are unknown, we can estimate the safe distance, transmission power broadcast radius, respectively, by

$$\hat{S}_i = (\tau + \delta)V_{\max} + l(V_{\max}, D_r, V_{\max}/D_r) + L - M_i \,,$$

$$\hat{T}_i = \hat{S}_i + \tau \max\{V_i - V_{\min}, 0\} \,,$$

and

$$\hat{B}_i = (1+\varepsilon)\hat{T}_i \,,$$

where $V_{\max}$ denotes the maximum velocity (or upper speed limit), $V_{\min}$ denotes the minimum velocity (or lower speed limit), and D_r is the regular deceleration. Note that the optimal value of ε can be turned by simulation or some rational function. The above models are also applicable to any vehicle C_i in a platoon. In such a case, the C_{i-1} presents the vehicle that has received a warning message from a vehicle ahead (e.g. C_{i-2}).

IV. SIMULATIONS

In this section, we conduct simulations to evaluate the proposed mechanism. We use the ns-2 network simulator [14] to simulate a highway scenario, where 50 vehicles driving on a highway platoon toward the same direction. Vehicle emergency situations are created by forcing the vehicle at the front of the platoon (i.e. vehicle 0) to rapidly decelerate (8m/s^2), which triggers a CCA process by initiating a warning message. Any vehicle behind will decelerate at the regular rate (4.9m/s^2) whenever it has received a warning message for a driver reaction time, randomly chosen from 0.75s to 1.5s.

The transmission medium is IEEE 802.11 MAC. The broadcast throughput is throughput is 1Mbps and the maximum transmission range is 250m. We will compare the cases with and without the power control mechanism. In order to evaluate the performance under the same base, we employ the naive broadcast [10], a direction-ware broadcast protocol for CCA, to forward any warning message at the network layer. Other parameters used in our simulation are listed in Table 2, which are mostly adapted from [10]. Note that to add dynamics in our test vehicle speed and inter-car spacing have 10% variations. Besides, we assume the maximum speed ($V_{\max}$) and minimum speed ($V_{\min}$) are available to each vehicle so that each vehicle C_i can estimate its broadcast radius B_i. The channel fading factor ε is set as 0.1 in our test. All results are averaged from 10 runs.

TABLE II. PARAMETERS SETTINGS

Parameters	Values
Number of vehicles on each lane	50
Vehicle length	4m
Vehicle speed	32m/s ± 10%
Regular deceleration	4.9/m/s/s
Emergency deceleration	8/m/s/s
Inter-car spacing	[9.6 – 28.8] m ± 10%
Driver's reaction time	[0.75 – 1.5] s
Radio model	Two ray ground
MAC protocol	IEEE 802.11 DCF
Broadcast protocol	Naïve broadcast
Message size	20 bytes
Random wait time	[0 –10] ms
Simulation runs	10

Fig. 4 shows the number of collided vehicles under varied average inter-car spacing. We can see that there are no more than a half of collisions being avoided if each vehicle always transmits or forwards at the maximum transmission radius. Contrarily, by using the power control technique, the possibility of a car collision can be greatly reduced especially when the inter-car spacing is reasonably large.

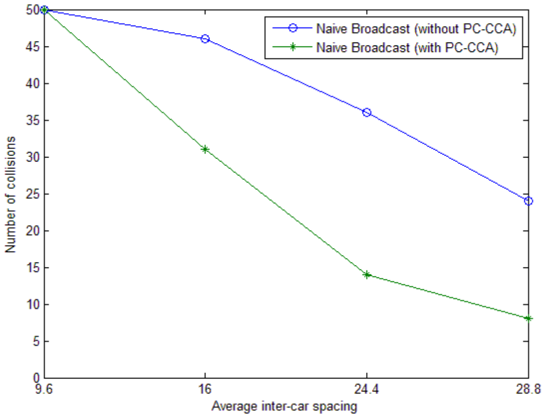

Figure 4. Number of collided vehicles under varied inter-car spacing

Such an impressive improvement is primarily the consequence of the reduced delivery delay. As shown in Fig. 5, with an average inter-car space of 28.8 m, the maximal delay required to delivery a warning message all vehicles can be confined in 8 ms if the PC-CCA is used. By contrast, the delivery delay without the PC-CCA increases drastically to the trailing vehicles, implying that more vehicles are not able to receive a warning message in time and brake safely.

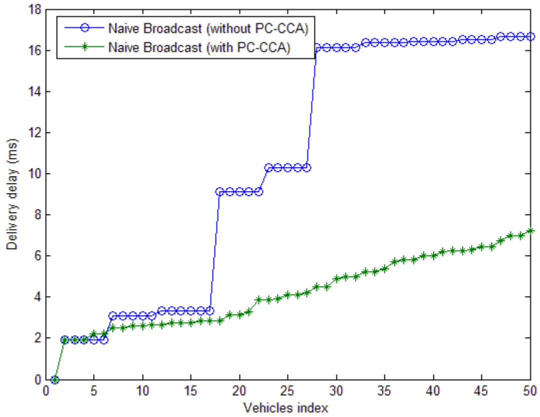

Figure 5. Delivery delay for each vehicle in the platoon (inter-car spacing: 28.8 m ± 10%)

V. CONCLUSION

In this paper, we have proposed an efficient broadcast mechanism for the CCA system using power control technique. The main idea for controlling power is based on the safe distance between vehicles. Simulation results show that our mechanism indeed helps to reduce delivery delay and car crashes.

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