行政院國家科學委員會專題研究計畫 期末報告

以安全、節能及遊憩為目的之車載網路系統--子計畫三：車載網路之位置感知服務：設計一個結合汽車及自行車行動導覽遊憩之系統(3/3)

計 畫 類 別 ：整合型
計 畫 編 號 ：NSC 100-2219-E-009-002-
執 行 期 間 ：100 年 08 月 01 日至 101 年 08 月 31 日
執 行 單 位 ：國立交通大學資訊工程學系（所）

計 畫 主 持 人 ：曾煜棋
共 同 主 持 人 ：張馨文、吳宗修

報 告 附 件 ：出席國際會議研究心得報告及發表論文

公 開 資 訊 ：本計畫可公開查詢

中 華 民 國 101 年 11 月 03 日

中 文 摘 要 ： 隨著無線通訊與嵌入式微感知機電裝置(MEMS)技術的快速發展，在行車環境利用無線通訊技術來發展車載感測網路(VSN)已成為可能。一般車載感測網路是由數個被裝載在車輛上的感測裝置，用來收集環境資訊或利用已偵測的資料來達成特定目的，例如: 車輛追蹤、防碰撞系統、環境監測、行動監控、以及車載安全等。因此，在第一年裡，本計畫開發一個新型車載監視與感測系統，整合各式感測裝置技術、無線通訊技術與車間通訊功能，以達成車載安全與車輛追蹤的目的。在第二年的計畫執行中，我們提出了在道路上的每台車輛均配備了影像攝影機並結合車牌辨識技術來識別可疑車輛(例如贓車)，以及利用車載無線通訊介面與車間通訊方式來協同追蹤可疑車輛和快速回報此發現給附近的警車。在第三年計畫裡，我們提出了一個VSN(vehicular sensor network)的網路架構，利用移動性的車輛在微環境下來蒐集空氣的品質(micro-climate monitoring) 。

中文關鍵詞： 汽車防盜、IEEE 802.15.4、監視系統、車載感測網路、車輛追蹤、特定短距通訊、車牌辨識、車載監控網路、車載追蹤、車載無線存取微環境偵測、機會式通訊、滲透式通訊、車載感測網路、無線感測網路

英 文 摘 要 ： The rapid progress of embedded micro-sensing MEMS and wireless communication technologies has made vehicular sensor networks (VSNs) possible. A VSN normally consists of a number of sensors placed on a vehicle to collect environment data and utilizes these sensed data for various purposes. Examples include vehicle tracking, crash prevention, and mobile surveillance. In the first year project,, we are interested in taking advantage of the current 3G/3.5G mobile systems to enrich user interaction in a VSN. Our goal is to develop a surveillance and sensing system for car security and tracking applications. In the second year project, we propose that 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 the third year project, we propose a VSN architecture to collect and measure air quality for microclimate monitoring in city areas.

英文關鍵詞： Burglarproof, IEEE 802.15.4, Surveillance, Vehicular Sensor Network, Vehicle Tracking, Dedicated Short Range Communications, License Plate Recognition, Vehicular Surveillance Network, Vehicle Tracking, Wireless Access in Vehicular Environments Micro-climate monitoring, Opportunistic communication, Pervasive computing, Vehicular sensor network, Wireless sensor network

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

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計畫參與人員：陳怡秀、陳羿丞、吳建澄、邱俊瑋

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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□涉及專利或其他智慧財產權，□一年□二年後可公開查詢

執行單位：國立交通大學資訊工程系

中 華 民 國 101 年 10 月 31 日

摘要

隨著無線通訊與嵌入式微感知機電裝置(MEMS)技術的快速發展，在行車環境利用無線通訊技術來發展車載感測網路(Vehicular Sensor Network , VSN)已成為可能。一般車載感測網路是由數個被裝載在車輛上的感測裝置，用來收集環境資訊或利用已偵測的資料來達成特定目的，例如: 車輛追蹤、防碰撞系統、環境監測、行動監控、以及車載安全等。因此，在第一年裡，本計畫開發一個新型車載監視與感測系統，整合各式感測裝置技術、無線通訊技術與車間通訊功能，以達成車載安全與車輛追蹤的目的。在第二年的計畫執行中，我們提出了在道路上的每台車輛均配備了影像攝影機並結合車牌辨識技術來識別可疑車輛(例如贓車)，以及利用車載無線通訊介面與車間通訊方式來協同追蹤可疑車輛和快速回報此發現給附近的警車。在第三年計畫裡，我們提出了一個VSN的網路架構，利用移動性的車輛在微環境下來蒐集空氣的品質(micro-climate monitoring) 。

關鍵字：汽車防盜、IEEE 802.15.4、監視系統、車載感測網路、車輛追蹤、特定短距通訊、車牌辨識、車載監控網路、車載追蹤、車載無線存取微環境偵測、機會式通訊、滲透式通訊、車載感測網路、無線感測網路

Abstract

The rapid progress of embedded micro-sensing MEMS and wireless communication technologies has made *vehicular sensor networks (VSNs)* possible. A VSN normally consists of a number of sensors placed on a vehicle to collect environment data and utilizes these sensed data for various purposes. Examples include vehicle tracking, crash prevention, and mobile surveillance. In the first year project,, we are interested in taking advantage of the current 3G/3.5G mobile systems to enrich user interaction in a VSN. Our goal is to develop a surveillance and sensing system for car security and tracking applications. In the second year project, we propose that 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 the third year project, we propose a VSN architecture to collect and measure air quality for microclimate monitoring in city areas.

Keywords: Burglarproof, IEEE 802.15.4, Surveillance, Vehicular Sensor Network, Vehicle Tracking, Dedicated Short Range Communications, License Plate Recognition, Vehicular Surveillance Network, Vehicle Tracking, Wireless Access in Vehicular Environments Micro-climate monitoring, Opportunistic communication, Pervasive computing, Vehicular sensor network, Wireless sensor network

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附錄：相關發表論文

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12. S.-C. Hu, Y.-C. Wang, C.-Y. Huang, and Y.-C. Tseng, "Measuring Air Quality in City Areas by Vehicular Wireless Sensor Networks", *Journal of Systems and Software*, Vol. 84, No. 11, pp. 2005-2012, Nov. 2011.

13. C.-C. Wu, L.-W. Chen, and Y.-C. Tseng, "Cooperative Localization for Power Saving in Vehicular Long-thin Networks", *National Computer Symposium (NCS)*, Dec. 2011.

14. L.-W. Chen, J.-H. Cheng, Y.-C. Tseng, L.-C. Kuo, J.-C. Chiang, and W.-J. Lin, "LEGS: A Load-balancing Emergency Guiding System Based on Wireless Sensor Networks", *IEEE International Conference on Pervasive Computing and Communications (PerCom)*, Mar. 2012.

獲獎資料:

1. Recipient of Outstanding Demo Award in the 6th IEEE International Conference on Mobile Ad-hoc and Sensor Systems, 2009. (IEEE MASS 2009 傑出展示獎）

2. Recipient of Best Paper Award in the 6th Workshop on Wireless, Ad Hoc, and Sensor Networks, 2010. (WASN 2010 最佳論文獎)

一、前言

車載資通訊(Telematics)的蓬勃發展，對汽車業和資訊科技產業來說，是雙重的利多消息。而車載資通訊研究範疇主要包含相連車輛之間或車輛與路邊裝置資訊的傳遞與運用的相關技術，利用這些資訊建立智慧型的交通管理系統或是行車輔助系統，以提升行車安全及行車效率為主要目的。隨著車載無線存取/特定短距通訊標準(Wireless Access in Vehicular Environments /Dedicated Short Range Communications, WAVE/DSRC)和嵌入式監視系統技術的快速發展，車輛可配備車上通訊裝置與影像攝影機來監控發生在道路上的各種事件，其應用包括車輛安全、煞車示警和市區監控等。由於現在都會區的車輛數暴增，使得二氧化碳的濃度急速增加，如何準確的監控二氧化碳濃度，相信是一個非常重要的課題。

二、研究目的

第一年計畫:

我們設計了一個新型車載監視與感測系統，其可以達成車載安全與車輛追蹤之目的，針對這樣的目的，我們把系統分成兩大模式，一為安全模式，另一為追蹤模式，對於安全模式，我們利用目前的 3G/3.5G 行動通訊技術來監測與接收車輛上嵌入式系統的資訊；對於追蹤模式，我們利用車牌辨識系統與 WAVE/DSRC 技術來持續追蹤可疑車輛，並回報給相關部門。針對以上所提的兩種模式，以下是其個別分析簡述:

1. 安全模式：在我們的設計規劃裡，當使用者停下車輛時，將會啟動此模式。對於車內安全的應用，要發展一個監控與感測系統，一般傳統的車輛保護，通常會仰賴路邊的攝影機來做影像記錄，對於這樣的設計，會存在兩個問題，第一，要識別目標車輛，需要從大量的候選資料做篩選，這將造成很大的工作負荷。第二，因為目標車輛不是事先已知，而且記錄的影像資訊又往往不夠清晰。更進一步，眾多的影像資訊，需要大量的人工勞力來過濾與查詢。對此，我們提出一個以 3G/3.5G加強功能的VSN，稱為車載監視與感測系統(Vehicular Surveillance and Sensing System, VS^3)，在使用者端，僅需要一個 3G/3.5G行動電話，在車輛端，要裝載CO_2感測裝置、影像攝影機、3G/3.5G通訊模組和嵌入式系統開發板。在嵌入式系統開發板上，其主要是請求命令與溝通協調各模組，VS^3主要提供以下特色:

(1) event-driven 模式，主要的事件來自於各模組偵測異常。

(2) 事件分為異常CO_2空氣品質、車載防盜、異常聲音偵測。

(3) 支援文字或多媒體的互動。

僅當定義之異常事件發生時，影像攝影機將會被驅動來拍照或影像記錄，因此，當沒有事件發生時，VS^3可以避免不必要的影像記錄，而增進圖片/影像品質。對於應用場景包含了異常CO_2偵測、車載防盜、異常聲音偵測，可用來驅動短簡訊服務(SMS)、多媒體簡訊(MMS)或是互動式影像電話給車主。所以，VS^3描述了一個新的車載安全與車載竊盜的模板。

2. 追蹤模式：在我們的設計規劃裡，當使用者行駛期間，將會啟動這模式。對於追蹤模式的應用，我們主要專注於追蹤贓車或可疑車輛並且通報給警車或是負責的車輛。針對一般對於車載追蹤的做法，都要建置大量的 Roadside Unit (RSU)結合感測器於一般道路旁，並與車載上的 On-Board Unit (OBU)通訊，但這樣將導致建置大量的 Roadside Unit (RSU)，同時相對地提高了建置成本，但對於我們設計方法的最大好處是避免了建置 RSU 成本。此外，我們的方法最特別的地方是利用了 Wireless Access in Vehicular Environments /Dedicated Short Range Communications (WAVE/DSRC)去增強車輛間在高速移動中的通訊能力。

第二年計畫:

在本計畫中，我們對於可疑車輛追蹤與回報的問題定義如下，每個無線通訊介面的通訊範圍為R，每一台車輛i持續識別其正前方的車輛v_f是否為可疑車輛v_s。我們的目標是設計出高效率的機制來協同式追蹤已被識別的v_s，並在追蹤期間於每個經過的交叉路口來回報v_s最新的位置給v_p，回報訊息m_r是以多節點(Multi-hop)傳送方式導引至附近的v_p，當v_p接收到m_r後，便可重建v_s的移動軌跡，以及儘快抵達v_s所在位置以採取必要的處理措施，以下是我們所設計之可疑車輛追蹤與回報機制的目標：

- 追蹤工作換手(Tracking Handoff)：車道改變或路口轉向時可將追蹤工作換手至鄰近車輛以持續追蹤v_s。
- 交叉路口偵測(Intersection Detection)：無需數位地圖輔助即可偵測出所經過的交叉路口以回報v_s最新位置給v_p。
- 位置回報廣播(Location Reporting)：根據鄰近車輛位置分佈來設計v_s位置回報方式以減少m_r的重廣播數量。
- 回報訊息導引(Message Guiding)：根據v_p所經過之位置來將m_r導引至最近的v_p以減少位置回報的訊息負擔(Overhead)。

第三年計畫:

能在市區隨時掌握二氧化碳的濃度和變動率，相信對於一些環保的研究課題是相當有幫

助的。由上述前言我們可以進而推出一個構想，就是利用車載網路來監控市區內二氧化碳的濃度。在下面的報告裡，我們利用了一個微環境偵測的架構(micro-climate monitoring)，也就是說把要偵測的大範圍切成一些小區域，蒐集小範圍的二氧化碳，進而推估大範圍的二氧化碳濃度。我們希望解決下面兩項問題：

1. 如何適當的調整車子的資料回報率(reporting rates)，以減少網路的流量。

2. 如何有效的利用動態式通訊(opportunistic communication)來減少通訊的負載。

我們提出了兩個演算法分別來解決上述的問題。

1. 為了要解決車子回報率的問題，首先，把要蒐集二氧化碳的區域(例如:新竹市)切成許多的小方格(grid)，每塊小方格(grid)裡的車輛都要把二氧化碳濃度回報給伺服器。此種演算法就是要推估每塊小方格裡面每台車輛的資料回報率(reporting rates)。

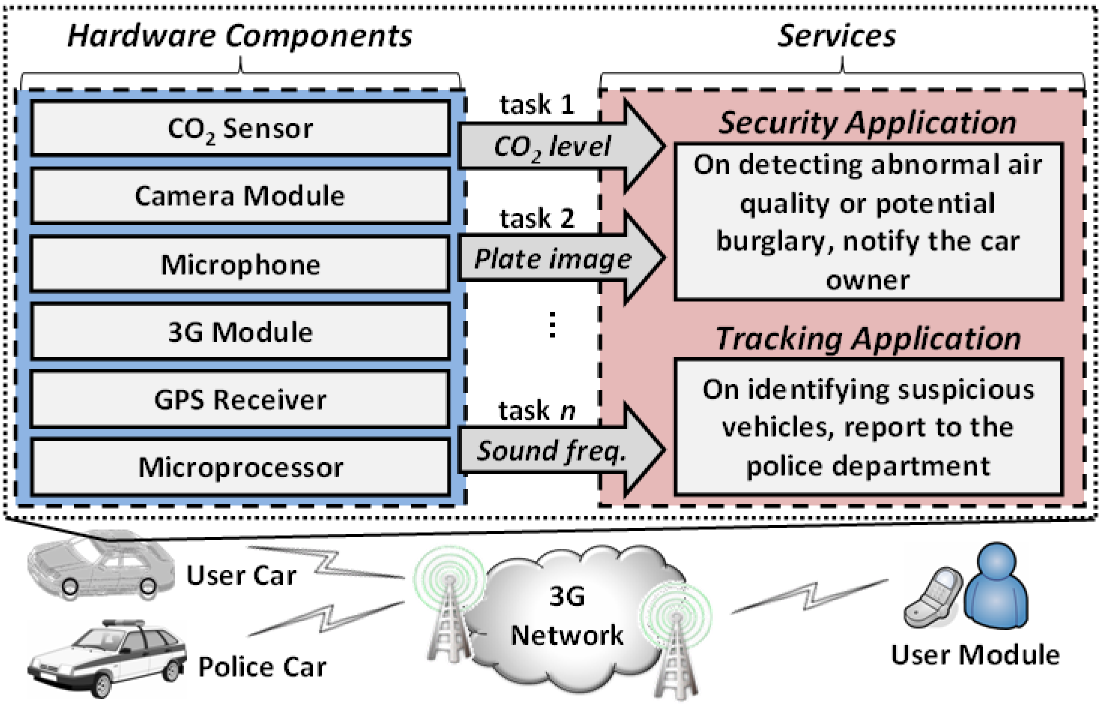
2. 由於車輛的移動具有隨機性，當一台車輛從一個小方格移動到另外一個小方格，如何獲取當地的資料回報率？也因此我們提出了另外一個演算法來解決這個問題。

三、研究方法

下面分別為三年計畫的研究方法，我們分別用條列式說明：

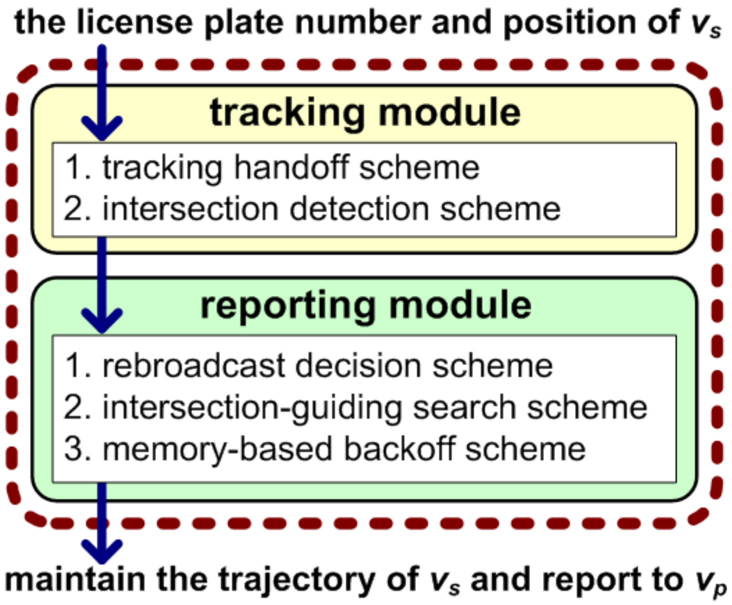
第一年計畫:(概述)

圖一顯示VS^{3}系統架構，在車輛端，它包含了CO_2感測裝置、影像攝影機、WAVE/DSRC通訊介面、3G/3.5G通訊模組和嵌入式系統開發板；在使用者端，則只需要一個 3G/3.5G行動電話。為了說明VS^{3}如何運作，我們將在以下用示意圖來描述車載安全、車載防盜、與車輛追蹤應用場景。



圖一. VS^{3}系統架構

第二年計畫:(概述)

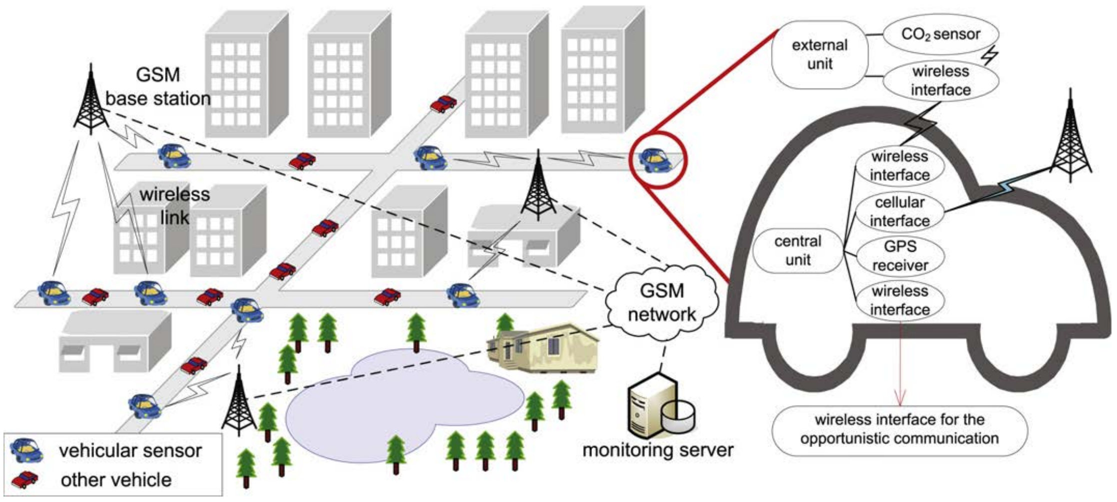


圖二、可疑車輛追蹤模組與回報模組

如圖二所示，我們針對可疑車輛追蹤與回報問題提出一個由Tracking Module和Reporting Module所構成的Infrastructure-less Framework，在Tracking Module方面，我們設計了Tracking Handoff機制和Intersection Detection 機制來持續追蹤v_s；在Reporting Module方面，我們設計了Rebroadcast Decision機制、Intersection-guiding Search機制、以及Memory-based Backoff機制來有效率地傳送m_r至附近的警車v_p。

第三年計畫:

圖三是針對演算法所提出的網路架構，此結構有下列元素構成。



圖三. 針對微環境偵測所提出的 VSN(Vehicular sensor network)網路架構

- Vehicular sensor：配備有二氧化碳偵測裝置的車輛，其中又分為External unit 和Central unit。
    1. External unit：External unit是放在車外的sensor裝置，主要是用來收集二氧化碳的資料。
    2. Central unit：Central unit是放在車內的裝置，由cellular interface(2G/3G/3.5G) 、GPS receiver以及兩個wireless interface構成。
- Other vehicle：沒有配備二氧化碳偵測裝置的車輛。
- GSM base station：2G網路基地台。
- GSM network：2G網路連線。
- Monitoring server：二氧化碳監控中心。

為了審查者能更詳細的聊解整個網路架構運作過程，我們用下列的情境模擬說明：

- Step1：假設有一台車輛(Vehicular sensor)已經收集到二氧化碳的資料。
- Step2：車輛外部的二氧化碳感應器會把資料傳給內部的Central unit。
- **Step3**：Central unit會根據通訊協定把資料傳給GSM base station。
- **Step4**：GSM base station再把資料傳給Monitoring server。

為了減少通訊時的負擔，每台車的Central unit可以藉由一些無線溝通介面(例如：Wifi)互相

形成無線隨意網路(Ad hoc Network) ，這樣可以增加機會式通訊的效能。然而，每台車可以藉由可以蒐集鄰近車輛的資訊，再把資訊傳送給二氧化碳監控中心。

在下一個部份的核心演算法，分成DRR(Dynamic reporting rates)和TOR(time-constraint opportunistic relay)兩部分來介紹。下面先介紹此演算法的動機。

- **DRR(Dynamic reporting rates)**：如果要預測一個都市的二氧化碳濃度，除了考慮二氧化碳的分布之外，還必須考慮各區域的車子密度，因為車輛會隨著時間而有所變動。DRR演算法就是要在每個小方格(grid)裡去預測此區域的資料回報率(Reporting rates) 。

- **TOR(time-constraint opportunistic relay)** ：當一台車從原本的方格G1移動到另外一個方格G2時，這台車可以幫忙G2裡面的車輛傳送資料，此時就可以降低G2方格裡的資料回報率。

由於二氧化碳的分布和變動是動態的，如果要精確的預估二氧化碳濃度，除了根據過去的數據資料來做參考還必須考慮下列兩點。

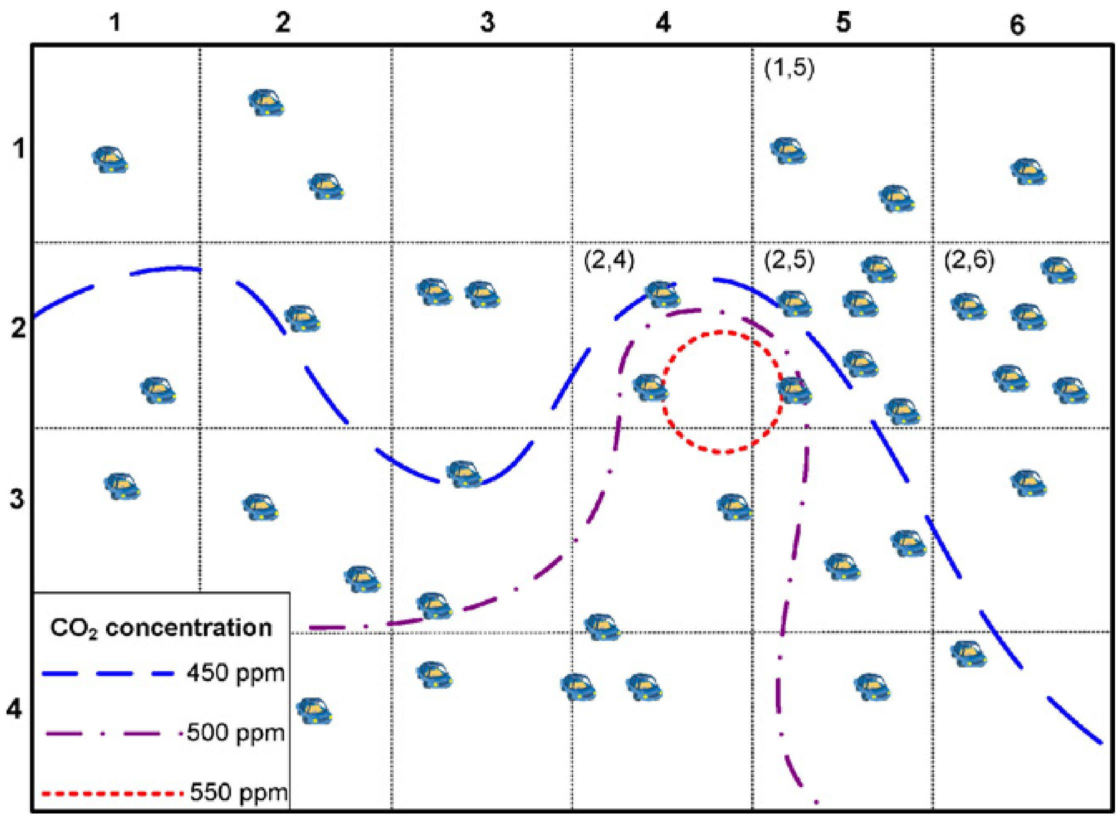
1. 當地區域的二氧化碳濃度。
2. 當地區域的車輛數。

下面部分開始介紹核心演算法。

✓ **DRR(Dynamic reporting rates)：**

DRR演算法主是要用來預估二氧化碳資料的回報率。首先，如果要預測一個大區域的二氧化碳濃度，先把此大區域切成許多小的區域(圖四) 。為了要準確的預測資料回報率，DRR又可再細分為兩種。

- Variation-based scheme：以模擬情境圖(圖四)的範例來看，座標(2,4)和座標(2,5)二氧化碳濃度偏高，因此，此地區的資料回報率會偏高；座標(1,5)和座標(2,6)的二氧化碳濃度偏低，因此，此地區的資料回報率會偏低。所以我們提出了一個數學式子，來推估該區域的資料回報量。



圖四. 情境模擬圖

這個數學式是一個線性的式子，利用一個變數和兩個常數來推估資料回報量。

$r_i^{var} = S_i^{var} / Vi$

$S_i^{var} = a_i^{var} \times б^{con}_i + b^{var}_i$

$б^{con}_i$：資料量的變數

r_i^{var}： 每台車需要的回報量

S_i^{var}：該區域資料回報總量

a_i^{var}和b^{var}_i：過去經驗的常數

Vi：該區域的車輛總數

- **Gradient-based scheme**：上述的數學式子並沒有考慮到單位距離二氧化碳濃度的變化量。假設有兩台車。他們之間距離很近，但是他們所在位置的二氧化碳濃度差異很大，所以這兩台車的之間單位濃度變化量很大，這是一個非常重要的資訊。因此我們提出另外一個利用梯度(gradient)的公式。

  首先，算出任意X和Y兩點的斜率(單位距離濃度的變化) ，公式如下：

  $\alpha(X,Y)=X-Y/dist(X,Y)$

  再來，推算出斜率總和，R_{high} 和R_{low}代表收集到高濃度和低濃度的車輛數：

  $\alpha^{avg}{}_i = \Sigma_{x\in R_{high},\, y\in R_{low}}\ \alpha(X,Y) / R_{high}\times R_{low}$

  接下來，再用Variation-based scheme的公式重新計算每輛車的回報量：

  $r_i^{gra}= S_i^{gra}/ Vi$

  $S_i^{gra} = a_i^{gra} \times\alpha^{gra}{}_i +b^{gra}{}_i$

✓ **TOR(time-constraint opportunistic relay)** ：當一輛車子原本的小方格G1移動到另外一個小方格G2時，可以藉由機會式通訊(opportunistic communication)來幫助G2內的車輛傳送資料。也因此，我們定義了下面的演算法。

1. 首先，當車輛X進入新的方格G2時，會定期廣播一個封包(HELLO Packet) 。這個封包括目前的方格ID還有一個att_x (attraction value)數值。

$att_x =rnd_x \times wgt_x$

rnd_x：0~1的隨機亂數

wgt_x：代表此節點需要傳到伺服器的資料量

2. 當X進入新的方格G2時，X可以藉由External unit和 Central unit來和G2內部的車輛Y互相交換訊息。

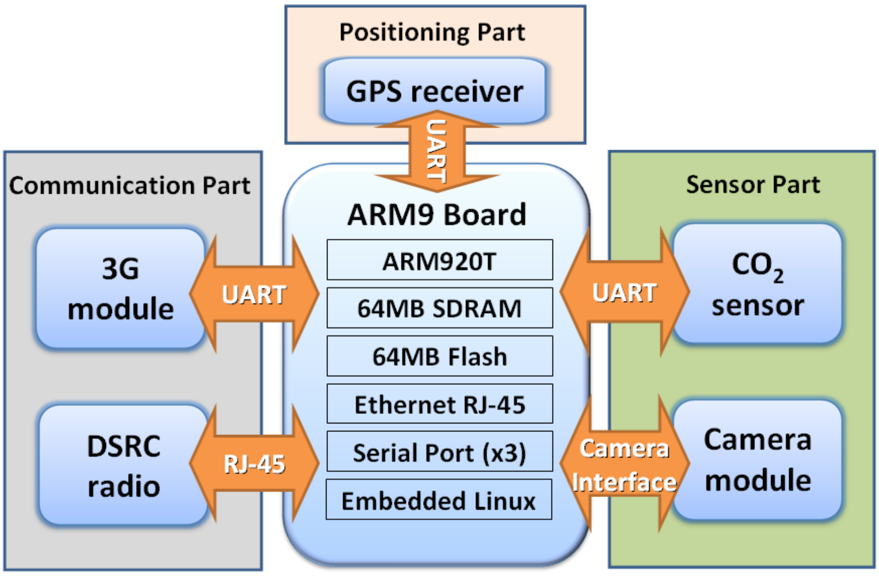
3. 當X和Y相遇時，而且$wgt_x < wgt_y$，X會把自己的資料量回報給Y，在傳送完畢後，X會把wgt_x改回零，而Y會把原本的wgt_y再加上wgt_x。

4. 當X如果因為一些障礙(如:大樓)而失去衛星導航信號，X會藉由通訊裝置和相鄰節點溝通來獲取自己的座標位置。

5. 最後，權重值不為零的點來傳送資料。

四、研究成果和實驗

在第一年的研究成果裡，我們實做了VS[3]裝置間的模組區塊橋接介面(圖五)。微處理器在VS[3]裝置是採用ARM9 開發板(Mini2440)，配有 3.5” TFT LCD、一個 400MHz 32-bit RISC處理器(ARM920T)、64MB SDRAM、64MB Nand Flash、2MB Nor Flash用於BIOS、三組序列傳輸阜、10/100M Ethernet RJ-45，Mini2440(圖六)可以執行embedded Linux和WinCE發展各式應用。



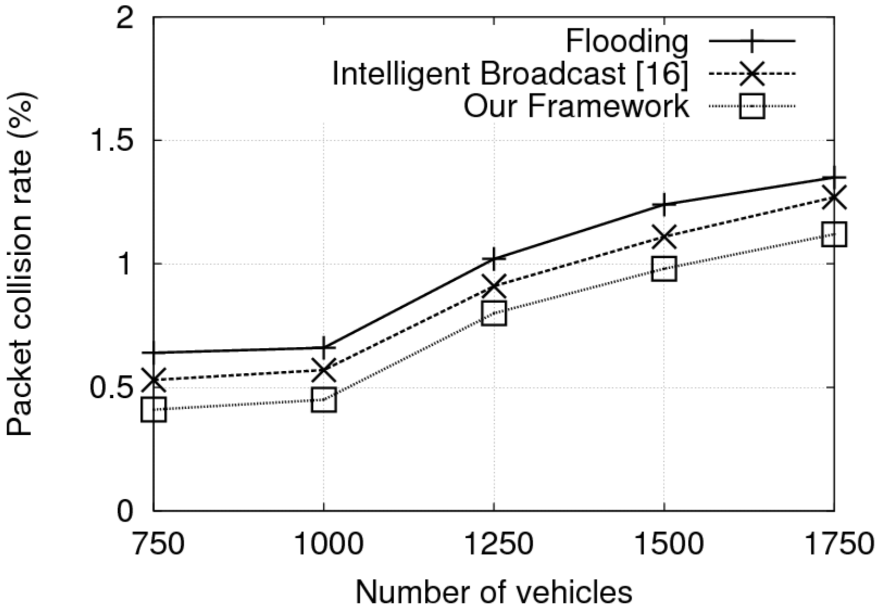
圖五. VS[3]模組區塊橋接介面

圖六. Mini2440 開發板硬體圖

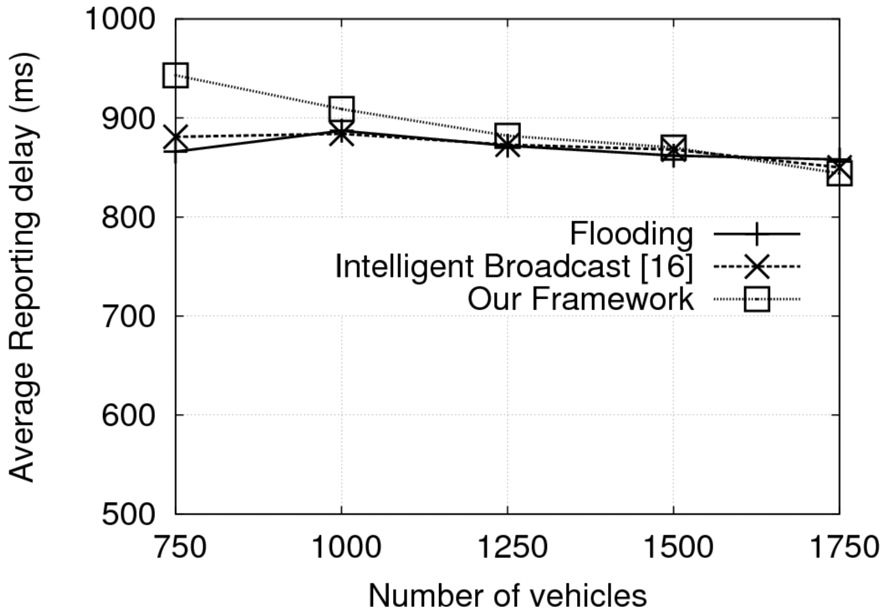
在第二年研究成果裡，們使用QualNet 5.0 網路模擬器並加入必要之修改來作模擬實驗的效能評估，如圖七所示，實驗環境拓樸為 5 km^2的城市區域，每個街區的大小為 1 km^2。所有車輛都均勻地散布在各個街道上，隨機選擇出一可疑車輛與一警車，每台車輛在路口隨機選擇前進、右轉、左轉三個方向其中之一。表一為我們所使用的模擬實驗參數，並設定t_u = 1 s、t_n = 10s、θ= 60°、 τ = 1、 ρ = 3、T = 30 s。圖七顯示在道路上不同的總車輛數所造成之封包碰撞率。圖八顯示平均回報延遲時間比較。由此可知，我們的演算法效能較好。

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
Beacon Interval	1 second
Tracking Handoff Timer	10 seconds
Transmission Range	300 m

表一.模擬實驗參數

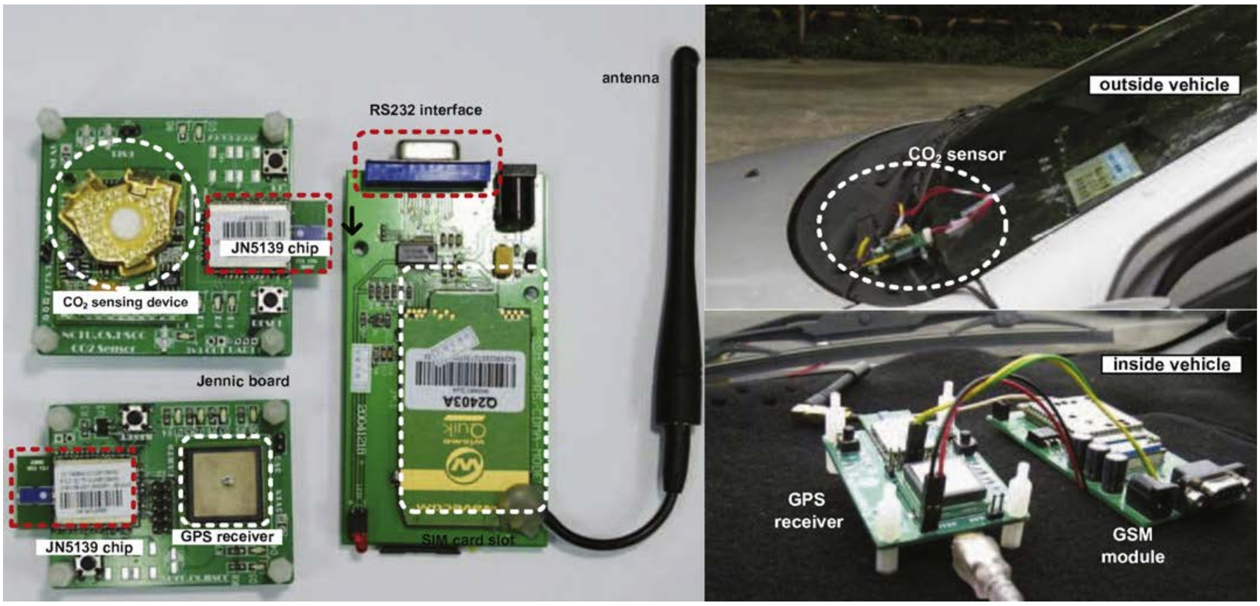


圖七.封包碰撞率比較



圖八. 平均回報延遲時間比較

在第三年研究成果裡，我們實做了一個偵測二氧化碳的硬體裝置(圖九)，圖的左方是監測二氧化碳的板子，圖的右方是External unit和Central unit的裝置。圖十則是這篇論文的封包傳輸格式。在模擬實驗方面，我們用C++和Matlab來驗證結果。表二是模擬參數，在模擬實驗裡，假設每傳出去一個資料花費一塊錢。由圖十一我們可以發現Variation-based scheme平均的花費會比Gradient-based scheme高，這是因為Gradient-based scheme有考慮到單位長度的濃度變化，所以所花費會比較低一點。而在預估誤差方面，兩者則是差不多。圖十二我們可以發現Variation-based scheme平均的花費會比Gradient-based scheme高，這是因為Gradient-based scheme有考慮到單位長度的濃度變化，所以所花費會比較低一點。而在預估誤差方面，兩者則是差不多。



圖九. 硬體實做裝置

Table 1
The default parameters of our simulator.

Parameter	Value
Number of streets	20
Area of the monitored region	12.8×12.8 km^2
Number of grids	16
Number of vehicular nodes	160
Velocity of vehicular nodes	30–60 km/h
CO_2 event rate	2CO_2 event
Maximum reporting rate	1/30 report/s
Minimum reporting rate	1/300 report/s
T	600 s
Length of a GSM short message	140 bytes
Cost per GSM short message	1 dollar

表二.模擬參數

format:

6 char	6 char	11 char	11 char
time	CO_2 reading	latitude	longitude

example:

184013	000700	02478.8722N	12099.8483E

[message format of a vehicular node]

format:

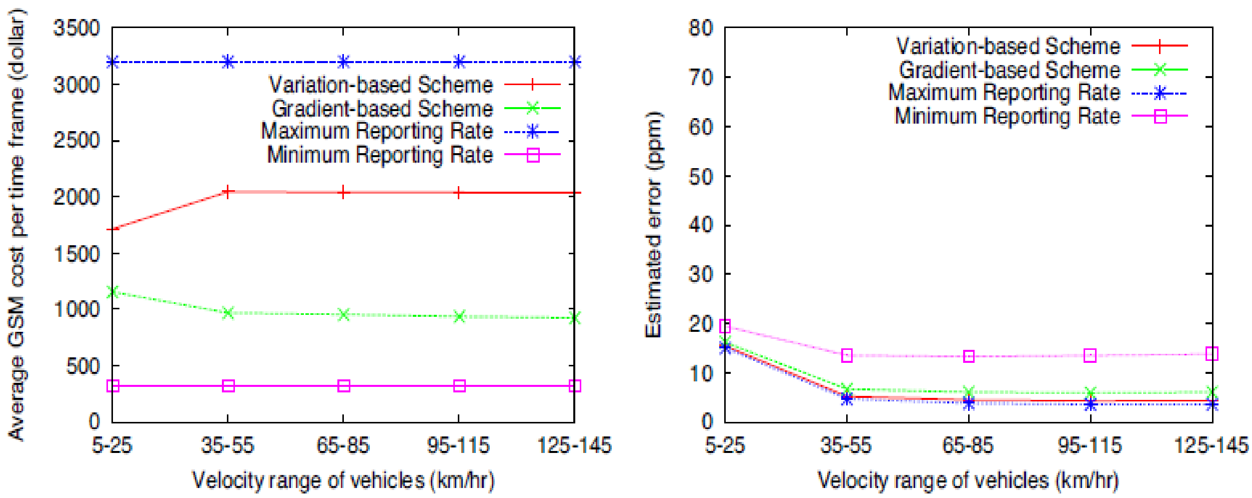
19 char	19 char	4 char	6 char
top-left latitude & longitude	bottom-right latitude & longitude	rate	expiration

example:

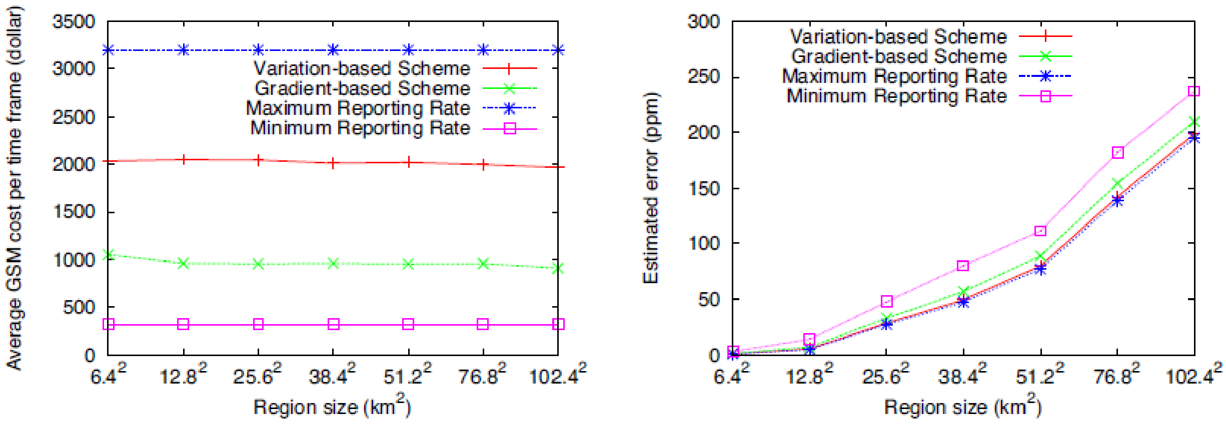
24789715N120996530E	24783968N121004276E	0020	190000

[message format of the server]

圖十. 封包傳輸格式



圖十一. GSM的花費和車輛數以及預估誤差率和車輛數的模擬圖



圖十二. GSM的花費和車輛數以及預估誤差率和車輛分布面積的模擬圖

五、結論與未來規劃

在第一年的計畫成果中，我們已開發了新型車載監視與感測系統，並以其為基礎發展了車載安全應用、車載防盜應用、以及車輛追蹤應用。在第二年度的計畫執行中，我們藉由車間通訊技術設計出一個無需搭配基礎建設的車載網路追蹤機制，其中包含追蹤換手(Tracking Handoff Scheme)、路口偵測(Intersection Detection Scheme)、決定重廣播設計(Rebroadcast Decision Scheme)、路口導引搜尋設計(Intersection-Guiding Search Scheme)和記憶式 backoff 設計(Memory-Based Backoff Scheme)。在這些機制的運作下，可以充分地減少網路上控制封包的負荷量和不必要的重廣播封包量。在第三年的計畫裡，我們把二氧化碳的硬體裝置實做出來，並且利用車輛的移動性和隨機性來蒐集二氧化碳濃度。先針對小區域的環境來回報，進而推估整個大區域的濃度。我們並且針對 VSN 提出了一個新的網路架構來做傳輸。為了考慮網路的傳輸量和車輛的移動性，我們也提出了新的數學式子來做效能評比和做改善。最後，透過模擬來驗證我們的演算法。在三年計畫執行期間，我們得到以下的成果：國內外會議與國際期刊論文發表 14 篇以及學術獎項 2 件，未來我們將朝向實務系統和標準開發規劃。

六、計畫成果自評

在三年計畫的執行過程中，已完成下列數項成果：(1)車載環境CO_2感測系統之設計與實作，本成果己發表於IEEE Sensors 2009 國際研討會；(2)新型車載監視感測系統之設計與實作，本成果己發表於IEEE MASS 2009 國際研討會，並獲大會頒發Outstanding Demo Award；(3)在所實作之車載監視感測系統上開發出新型車輛安全應用，本成果己發表於VTC/WiVEC Joint Telematics Workshop 2010 國際研討會；(4)在所實作之車載監視感測系統上開發出新型車輛追蹤應用，本成果己發表於ACM/IEEE IPSN 2010 國際研討會；(5)雙層式長鏈狀車載網路之高效率資料收集與散佈機制設計，本成果己發表於WASN 2010 研討會，並獲大會頒發Best Paper Award；(6)GoBike自行車隊通訊系統之設計與實作，本成果己於ACM MobiCom 2010 國際研討會進行雛型系統展示；(7)在所實作之自行車隊通訊系統上開發出新型擴增實境應用，本成果己發表於IEEE PerCom 2011 國際研討會；(8)車載感測網路中無需基礎設施輔助之車輛防追撞機制設計，本成果己發表於IEEE Communications Letters國際期刊；(9)以智慧型手機為基礎之單車旅遊紀錄系統設計與實作，本成果己發表於Digital Content and Multimedia Applications Conference 2011 研討會；(10)以車間通訊為基礎之可疑車輛追蹤與回報系統設計與實作，本成果己發表於Mobile Computing Workshop 2011 研討會；(11)基於車載網路以環境保護為目的之交通號誌控制機制，本成果發表於ACM SIGCOMM 2011 國際研討會；(12)以車載感測網路為基礎之都市空氣監控機制，本成果發表於Journal of Systems and Software國際期刊；(13)在車載長鏈狀網路以節能為目的之協同式定位機制，本成果發表於NCS 2011 研討會；(14)以無線感測網路為基礎之負載平衡緊急導引系統，本成果發表於IEEE PerCom 2012 國際研討會。

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VS^3: A Vehicular Surveillance and Sensing System for Security Applications

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***Abstract*—The *Vehicular Surveillance and Sensing System* (VS^3) is a 3G-based mobile device for car security applications. On the car side, it consists of a CO_2 sensor, a camera module, a 3G module, and a microprocessor. On the user side, only a 3G mobile phone is needed. VS^3 provides the following features: (i) it can be triggered by events detected on car, (ii) events can be abnormal air quality or potential burglary, and (iii) it supports text or multimedia interaction with users. Application scenarios include detecting an abnormal CO_2 level or potential car burglary, which triggers VS^3 to transmit SMS, MMS, or interactive video call to the vehicle owner, who can then monitor the car situation in return. VS^3 thus demonstrates a new car security and burglarproof prototype.**

Keywords: Burglarproof, IEEE 802.15.4, Surveillance, Vehicular Sensor Network, Wireless Network.

I. Introduction

The rapid progress of embedded micro-sensing MEMS and wireless communication technologies has made *vehicular sensor networks* (VSNs) possible. A VSN normally consists of a number of sensors placed on a vehicle to collect environment data and utilizes these sensed data for various purposes. Examples include vehicle tracking, crash prevention, and mobile surveillance [2], [3], [7].

In this work, we are interested in taking advantage of the current 3G or 3.5G mobile systems to enrich user interaction in a VSN. Our goal is to develop a surveillance and sensing system for car security applications. Traditional surveillance systems for vehicle protection 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.

We propose a 3G-enhanced VSN called *vehicular surveillance and sensing system* (VS^3). Only a 3G mobile phone is needed on the user side, whereas an integrated device with a CO_2 sensor, a camera module, a 3G module, and a microprocessor is need on the car side. The microprocessor is responsible for issuing commands and coordinating with other modules. VS^3 provides the following features: (i) it can be triggered by events detected on car, (ii) events can be abnormal air quality or potential burglary, and (iii) it supports text or multimedia interaction with users. Only when an event is dectected, the camera module is activated to capture images or record videos of that event. Thus, VS^3 can avoid recording unnecessary videos when nothing happens and improving image/video quality. Application scenarios include detecting an abnormal CO_2 level or potential car burglary, which triggers VS^3 to transmit SMS (short message service), MMS (multimedia message service), or interactive video call to the vehicle owner, who can then monitor the car situation in return. VS^3 thus demonstrates a new car security and burglarproof prototype.

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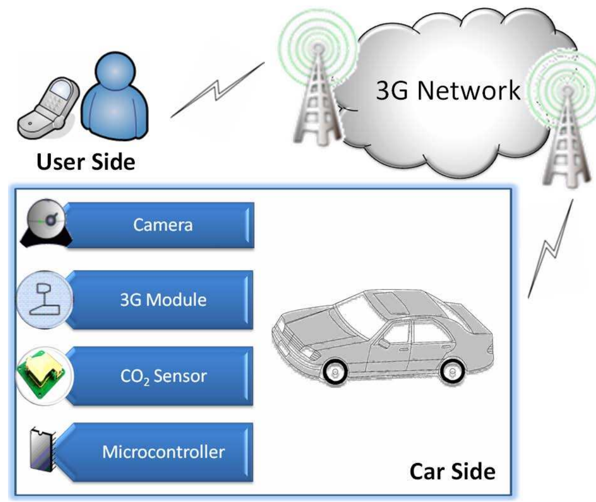

Fig. 1. System architecture of VS^3.

II. System Architecture

Fig. 1 shows the VS^3 architecture. On the car side, it consists of a CO_2 sensor, a camera module, a 3G module, and a microprocessor. On the user side, only a 3G mobile phone is needed. To illustrate how VS^3 works, we demonstrate a car security and a car burglarproof applications below. In

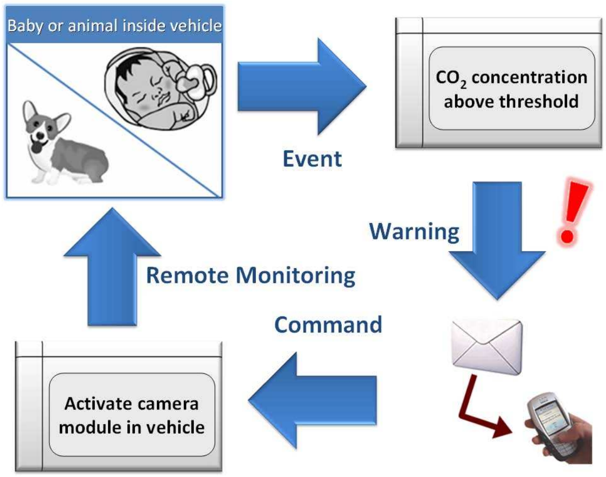

Fig. 2. A car security application.

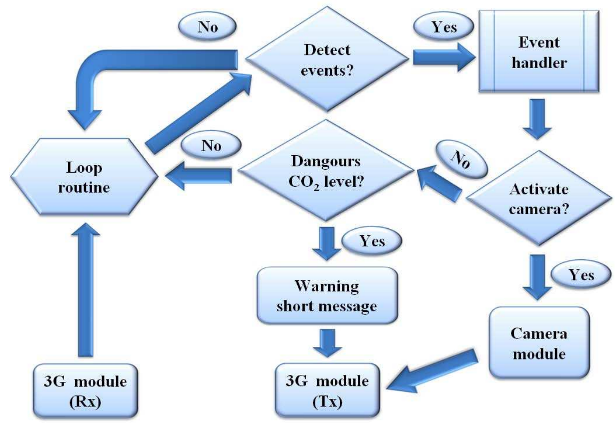

Fig. 4. Flowchart of VS^3.

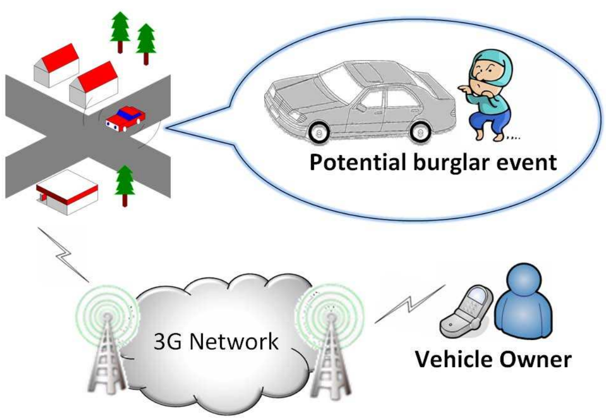

Fig. 3. A car burglarproof application.

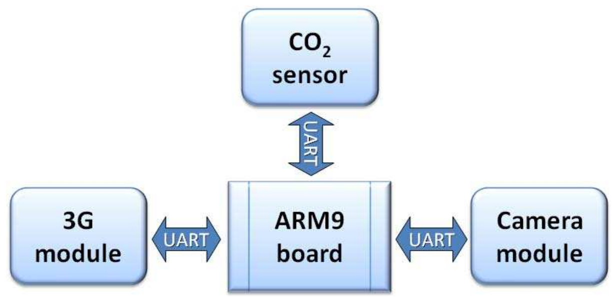

Fig. 5. Building blocks of the car unit.

the car security application in Fig. 2, after the driver parks the vehicle and activates the car unit, VS^3 will continuously check the CO_2 concentration in the vehicle for a predefined period. During this period, when it is found that the CO_2 concentration is beyond a dangerous threshold, VS^3 will send a short message to notify the predefined phone number (user unit). On receipt of the warning message, the owner can return a command short message to VS^3. According to the command, VS^3 activates the camera module and initiates a video call to the owner. Through the live video call, the user can monitor possible abnormal events (such as baby or animal forgotten in the vehicle) by his/her 3G phone. Therefore, lives can be saved in time by the help of VS^3.

In the car burglarproof application in Fig. 3, VS^3 notifies the owner as a potential burglar event is detected (such as door open). Since an immediate action is needed, VS^3 will directly record a video clip and send it to the owner via MMS. More importantly, the video clip is a critical clue and evidence to catch the thief. Fig. 4 shows the VS^3 flowchart.

Fig. 6. Mini2440 development board with a 3.5” TFT LCD.

Fig. 7. H-550EV CO_2 sensor integrated with JN5139.

Fig. 8. Wavecom Q2403A module.

III. Implementation Details

Fig. 5 shows the building blocks of the car unit. The microprocessor in the car unit is an ARM9 board (Mini2440 [4]) with a 3.5" TFT LCD as shown in Fig. 6, which has a 400MHz 32-bit RISC integer processor (ARM920T [1]), 64MB SDRAM, 64MB Nand Flash, 2MB Nor Flash with BIOS, three serial ports, and a 10/100M Ethernet RJ-45. In particular, Mini2440 can run embedded Linux and WinCE to develop diverse applications.

The CO_2 module has an H-550EV CO_2 sensor [5] integrated with Jennic JN5139 [6], which is mounted to Mini2440 via an UART interface. Our prototype is shown in Fig. 7. The CO_2 sensor module has 0$\sim$5,000ppm measurement range and $\pm$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.

The 3G module is currently implemented by a Wavecom Q2403A GSM/GPRS/CDMA module as shown in Fig. 8, which is controlled by Mini2440 via AT commands. It performs SMS, MMS, and video calls as instructed by the ARM9 board.

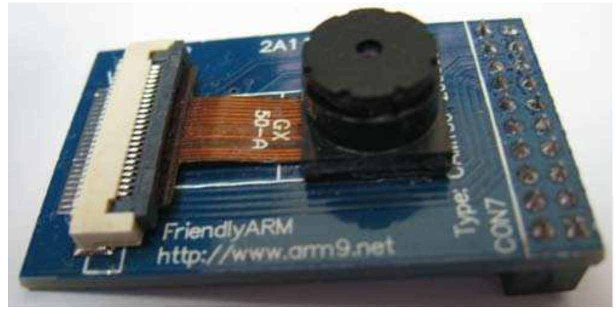

Fig. 9. CAM130 camera module.

The camera module is implemented by CAM130 as shown in Fig. 9. It is a CMOS optical sensor. Mini2440 can send a snapshot (record) command to CAM130. In return, a full-resolution, single-frame still picture (video) will be transferred to Mini2440 through the serial port.

In the CO_2 monitoring application, the concentration threshold is set to 1500ppm. We use AT commands to trigger the 3G module to send short messages. The car owner can return a short message with a specific command to ask the ARM9 board to initiate a video call back.

In the burglarproof application, besides a warning short message, a video clip is sent to the car owner as a multimedia message. The clip can be provided to polices as evidence in the future when needed.

IV. Conclusion

VS^3 integrates 3G communication and CO_2 sensing into surveillance technologies to support intelligent car security applications. The vehicle owner can be informed immediately as unusual events are detected on car. At the same time, the owner can remotely monitor the situation inside vehicle and then take proper actions if necessary. VS^3 can prevent vehicles form burglar or keep evidences to catch the thief. Furthermore, The baby or animal forgetfully left in the vehicle can be rescued in time by the assistance of VS^3. The future extension of VS^3 could be equipped more various sensors and form a VS^3 network to investigate cooperation issues and develop novel applications.

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A Vehicular Wireless Sensor Network for CO_2 Monitoring

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***Abstract*— Micro-climate monitoring usually requires deploying a large number of measurement tools. By adopting *vehicular wireless sensor networks (VSNs)*, we can use fewer tools to achieve fine-grained monitoring. This work proposes a VSN architecture to realize micro-climate monitoring based on GSM short messages and availability of GPS receivers on vehicles. We demonstrate our prototype of a ZigBee-based car network to monitor the concentration of carbon dioxide (CO_2) gas in areas of interest. The reported data are sent to a server, which is integrated with Google Maps as our user interface. Since mobility of these vehicles is not controllable and sending short messages incurs charges, we also design an on-demand approach to adjust vehicles' reporting rates to balance between the micro-climate accuracy and the communication cost.**

I. Introduction

We are interested in monitoring *micro-climate*, which means fine-grained environmental data in the scale of tens to hundreds of square meters. Typically, climate means macro-climate, which means data in the scale of tens to hundreds of square kilometers. Monitoring micro-climate requires a large number of measurement tools. By adopting vehicles (e.g., taxis and buses) as carriers with sensing devices and wireless communication interfaces, we can use fewer measurement tools to achieve fine-grained monitoring. We refer to such systems as *vehicular wireless sensor networks (VSNs)*.

This paper proposes a VSN architecture to monitor micro-climate based on GSM short messages and geographic information of vehicles. We show our prototype to monitor the concentration of carbon dioxide (CO_2) gas in areas of interest. CO_2 gas is a critical index of air quality and global warming. In our prototype, a vehicle is equipped with a CO_2 sensor, a GPS receiver, and a GSM module, which form a ZigBee-based intra-vehicle wireless network. Each of such vehicles thus serves as a *vehicular sensor*. These vehicular sensors roam inside the area of interest and periodically report their sensed data through GSM short messages. The reported data is collected by a server, which is integrated with Google Maps [1] to demonstrate the result.

Since the mobility of these vehicles is not controllable and sending short messages incurs charges, how to adjust vehicles' reporting rates to balance between the monitoring accuracy and the communication cost is a challenge issue. We propose an adaptive approach to dynamically change the reporting rates of vehicular sensors on their readings. In particular, the data variation in a grid is considered to adjust the reporting rate.

The major contributions of this paper are two-fold. First, we propose a new architecture based on VSNs to support fine-grained micro-climate monitoring by using a small number of measurement tools. A prototype is also implemented to verify the practicability of the proposed architecture. Second, based on the proposed architecture, we also design an adaptive approach to adjust the reporting rates of vehicles to balance monitoring quality and communication cost.

The rest of this paper is organized as follows. Section II surveys some related work. Section III presents the proposed VSN architecture. Our prototyping experiences are given in Section IV. Section V concludes this paper.

II. Related Work

Wireless sensor networks have been widely applied to surveillance or monitoring scenarios [2][3][4]. However, they do not discuss how to exploit mobility to reduce monitoring cost. Mobile sensor deployment and dispatch have been intensively studied in [5]. BikeNet [6] deploys multiple types of sensors on bicycles to analyze various road information for sharing of cyclists' experience. MobEyes [7] adopts cameras and chemical sensors to monitor pollution on streets, and vehicles may exchange their sensing data when they meet with each other. Compared to these work, our work is unique in trying to reach a balance between message overheads and sensing quality, under dynamically changing environments.

III. The Proposed VSN Architecture

Fig. 1 illustrates the proposed VSN architecture for micro-climate monitoring. It contains a monitoring server, several vehicular sensors, and GSM networks. Each vehicular sensor is equipped with a CO_2 sensor, a GSM module, and a GPS receiver and periodically reports its sensed CO_2 concentration and its current location to the server through GSM short messages. The monitoring server then calculates the distribution of CO_2 concentration and renders the result on Google Maps. According to the observed distribution and the vehicle density, the server will ask sensors to adjust their reporting rates. For each vehicular sensor, the intra-vehicle network is a ZigBee network.

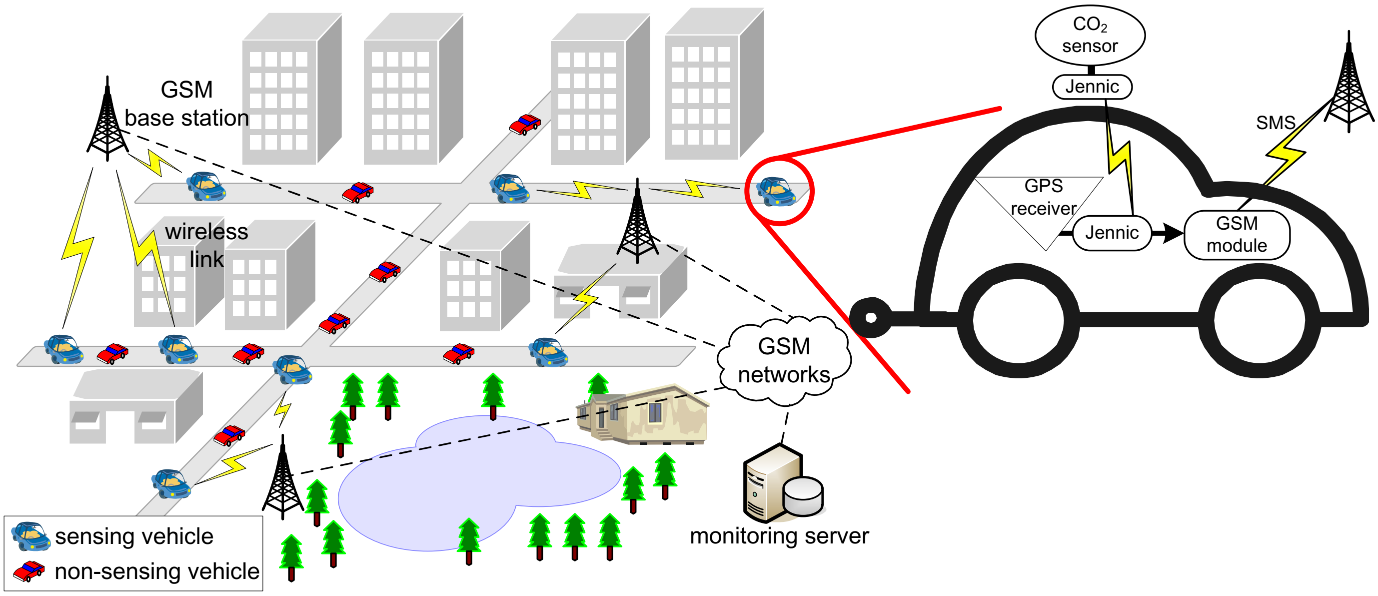

Fig. 1. The proposed VSN architecture for micro-climate monitoring.

We adopt GSM short message service since it is a mature technology. It can be easily extended to 3G or 3.5G technologies. Since sending short messages incurs charges, we need an adaptive approach to adjust sensors' reporting rates. The basic idea is to partition the monitoring area into grids. Each grid has its own reporting rate according to the variance of CO_2 concentration and vehicle density in that grid. Let $r_k^{\max}$ and $r_k^{\min}$ be the maximum and minimum CO_2 readings of the k-th grid, respectively, and $P_k^{\max}$ and $P_k^{\min}$ be the positions in grid k where these two readings are reported, respectively. We define the variance of gird k is as

$$\rho_k = \frac{r_k^{\max} - r_k^{\min}}{d(P_k^{max}, P_k^{min})}, \tag{1}$$

where $d(P_k^{max}, P_k^{min})$ is the distance between P_k^{max} and P_k^{min}. Intuitively, ρ_k indicates how drastic the change of readings is. The number of vehicular sensors in grid k can be estimated by $\delta_k = \frac{n_k}{\mu_k \times t}$, where n_k is the number of sensing reports received in grid k during an observation interval t and μ_k is the current reporting rate in grid k.

Intuitively, a higher reporting rate μ_k should be set when the variance ρ_k is higher, and vice versa. For example, in Fig. 2, the variances in grids (2, 4) and (2, 5) are more significant, so higher reporting rates are required. Since grid (2, 5) has more vehicles, its rate can be slightly lower than that of grid (2, 4). Similarly, the variances in grids (1, 5) and (2, 6) are less significant, so lower reporting rates should be adopted to reduce messages. Since grid (2, 6) has more vehicles, its rate can be slightly lower than that of grid (1, 5).

Based on the above observation, our adaptive approach works as follows. Assume that each round is of length t minutes. Let $\mu_{\max}$ and $\mu_{\min}$ be the maximum and minimum allowable reporting rates, respectively. Consider round i. Let ρ_k^i, δ_k^i, and μ_k^i be the variance, the estimated number of vehicles, and the reporting rate at round i in grid k, respectively. We propose to compute the reporting rate μ_k^{i+1} based on the observed results in rounds $i-1$ and i. Specifically, we compute μ_k^{i+1} at the beginning of round $i+1$ as follows:

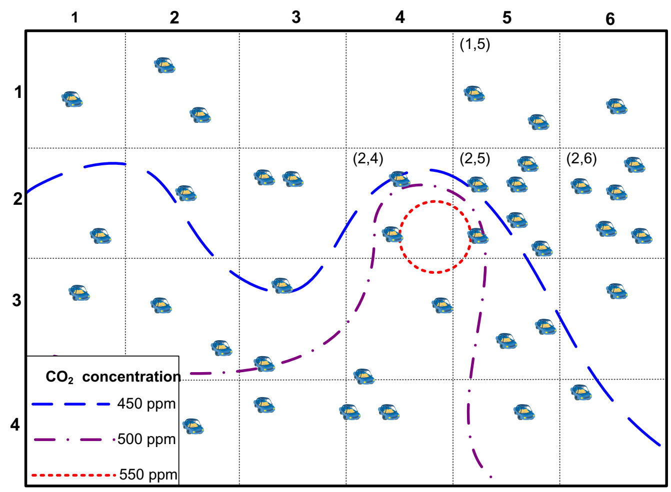

Fig. 2. An example of grid architecture and reporting rate adjustment.

$$\mu_k^{i+1} = \begin{cases} \min\{\mu_{\max}, tmp\} & \text{if } tmp > \mu_k^i \\ \max\{\mu_{\min}, tmp\} & \text{otherwise} \end{cases}, \text{where} \tag{2}$$

$$tmp = \left(\frac{\rho_k^i}{\rho_k^{i-1}} \times \frac{\delta_k^{i-1}}{\delta_k^i} \right) \times \mu_k^i. \tag{3}$$

The value of μ_k^{i+1} should be sent to vehicles at the beginning of round $i+1$.

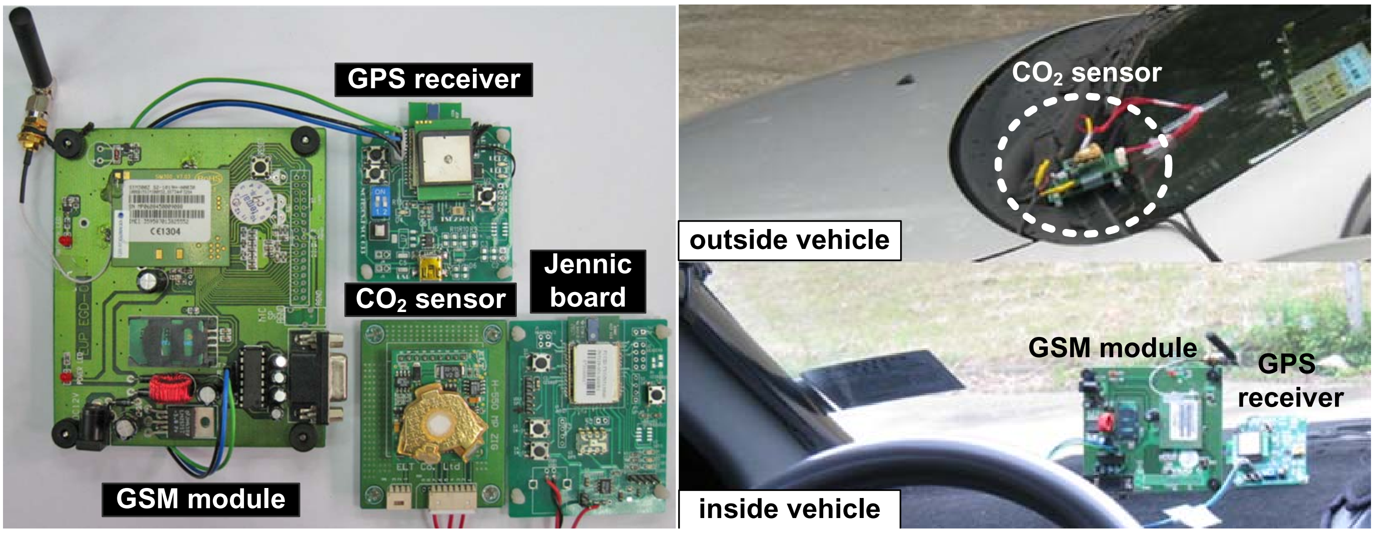

Fig. 3. The snapshots of hardware components.

IV. Prototyping Experiences

We have implemented a 16-vehicle prototype to collect CO_2 concentration in Hsin-Chu Science Park, Taiwan. Each vehicle is equipped with the following hardware components (as shown in Fig. 3):

1) Jennic board: It is a microprocess with a wireless module. A Jennic board contains a JN5139 chip [8], which has a 32-bit RISC processor, a fully compliant 2.4 GHz IEEE 802.15.4 [9] transceiver, 192 KB of ROM, and 96 KB of RAM. We use the ZigBee protocol [10] for inter-board communication.
2) GPS receiver: We adopt the uPatch300 GPS module [11]. It can provide geographic location with accuracy ≤ 1.8 meters. Its reporting rate is set to 1 second.
3) CO_2 sensor: We adopt the H-550EV CO_2 sensor module [12]. It will sample CO_2 concentration every 3 seconds. Its detectable range is from 0 to 5,000 ppm with error range of ± 30 ppm.
4) GSM module: We adopt the SIM300 GSM module [13], which supports the tri-band GSM/GPRS communication on frequency bands of 900 MHz, 1,800 MHz, and 1,900 MHz.

Fig. 3 shows the snapshots of these components. The CO_2 sensor is installed outside the vehicle, while the GPS receiver and the GSM module are installed inside the vehicle. Each of the GPS receiver and the CO_2 sensor is attached to a Jennic board, so they can communicate with each other through a ZigBee wireless link. The GPS receiver is connected to the GSM module through an RS232 wired interface. The CO_2 sensor reports its readings periodically at a fixed rate to Jennic board inside the vehicle. The Jennic board will then average these readings, combine them with the current location of the vehicle, and report to the monitoring server via GSM short messages. The reporting will follow the requested rate.

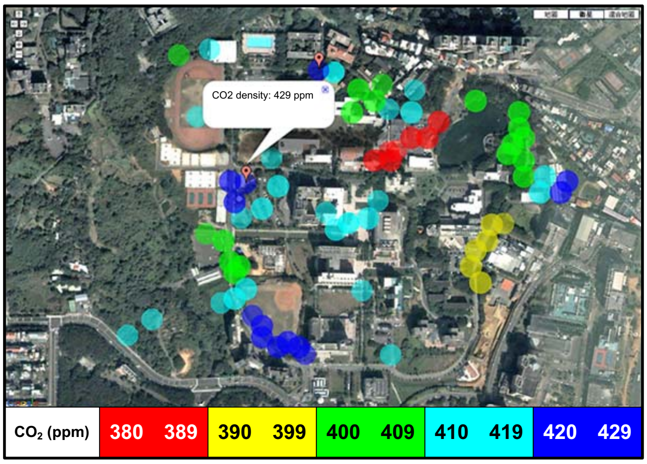

Fig. 4. A snapshot of CO_2 concentration at the NCTU campus.

Fig. 4 demonstrates our monitoring results at the National Chiao-Tung University (NCTU) campus. The monitoring region is approximately 80 hectares and is partitioned into 5×4 grids. The observed CO_2 concentration ranges from 380 ppm to 429 ppm. Each circle indicates the monitoring position and its color represents the corresponding level of CO_2 concentration. Users can click on each circle to obtain the detailed data.

V. Conclusions and Future Work

In this paper, we have proposed a new architecture based on VSNs for micro-climate monitoring. Through GSM short messages and geographic locations of vehicles, we can use a small number of vehicles to realize a fine-grained monitoring in urban areas. To balance between the monitoring quality and the message cost, we have designed an adaptive approach to adjust the reporting rates of sensing vehicles according to the variance of sensing readings and the density of vehicles in each grid. We have also demonstrated the prototype of a ZigBee-based intra-vehicle wireless network.

ACKNOWLEDGEMENT

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A Vehicular Surveillance and Sensing System for Car Security and Tracking Applications

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ABSTRACT

In this paper, we propose a *Vehicular Surveillance and Sensing System* (*VS*^{3}), which targets at car security and tracking applications. VS^3 can be triggered by events detected inside or outside a car, such as abnormal air quality, potential burglary, and identification of some target vehicles (such as stolen cars). Via a 3G module, a user can interact with VS^3 via multimedia communications. For security applications, we show how VS^3 detects an abnormal CO_2 level or potential car burglary, notifies the vehicle owner, and then interacts with the owner. For tracking applications, we show how VS^3 identifies potential stolen vehicles, transmits reports to the police department, and get neighboring cars involved to cooperatively track suspicious vehicles. This paper demonstrates our current prototype.

Categories and Subject Descriptors: C.2.1 [Network Architecture and Design]: Distributed networks

General Terms: Algorithms, Design, Management

Keywords: Burglarproof, Surveillance, Vehicle Tracking

1. INTRODUCTION

The rapid development of micro-sensing MEMS and wireless communication technologies has made *vehicular sensor networks* (VSNs) possible. In a VSN, vehicles carry sensors to collect surroundings data and they cooperate with each other to utilize these sensed data for various purposes, such as crash prevention, surroundings monitoring, and mobile surveillance.

On the other hand, 3G/3.5G mobile systems are quickly developing. This would greatly enrich the interaction among users and vehicles. For example, a burglarproof system can provide video calls between a user and an on-board unit. As another example, traditional surveillance systems for vehicle monitoring rely on roadside cameras for video recording. However, it requires a lot of labors to go through these videos and huge efforts to distinguish targets from other irrelevant vehicles. With the cooperation of 3G/3.5G systems and VSNs, such video-recording work can be done in an on-demand manner via on-street vehicles.

In this work, we propose a 3G-enhanced VSN called *vehicular surveillance and sensing system* (*VS*^{3}). VS^3 can be triggered by events detected by a car. We will show how

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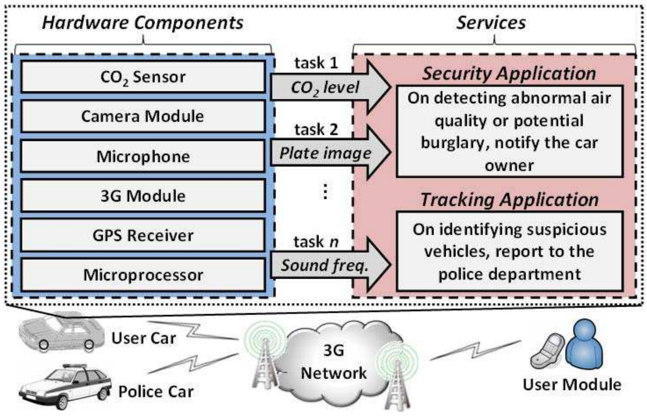

Figure 1: System architecture of VS^3.

events of abnormal air quality, potential burglary, and identification of some suspicious vehicles (such as those stolen cars identified by the police department) trigger the surveillance module of VS^3 in an on-demand manner. Thus, VS^3 can avoid recording unnecessary videos. Alternatively, for simpler events, VS^3 can transmit SMS (short message service) or MMS (multimedia message service) to vehicle owners, who can then decide whether to initiate a video call. This paper demonstrates our current prototype.

2. SYSTEM ARCHITECTURE

Fig. 1 shows the architecture of VS^3. On the car side, it consists of a CO_2 sensor for detecting the CO_2 level inside the vehicle, a microphone for detecting unusual sound frequencies inside the vehicle, a GPS receiver, camera modules for taking photos or recording videos inside and outside the vehicle, a 3G module for making SMS, MMS, or interactive video calls, and a microprocessor for controlling all these components. On the user side, only a 3G mobile phone is needed to receive warning short messages, pictures, video clips, or interactive video calls from the on-board unit.

VS^3 targets two types of vehicular applications: security and tracking. In the security part, we propose two scenarios in Fig. 2(a) and Fig. 2(b). In Fig. 2(a), after a vehicle is parked, VS^3 will continuously check the CO_2 concentration in the vehicle for a predefined period. During this period, if there is no abnormal CO_2 concentration, it implies there is no baby or animal in the car. So the CO_2 sensor can be shut down to save energy. If it find that the CO_2 concentra-

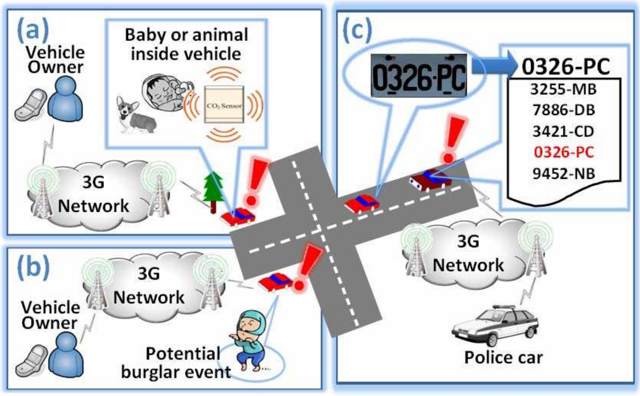

Figure 2: Scenarios of security and tracking applications.

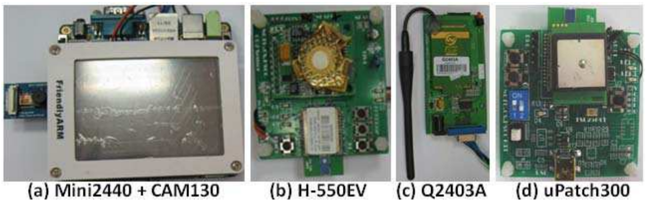

Figure 3: VS^3 hardware components.

tion is beyond a dangerous threshold, VS^3 will send a short message to a predefined phone number. The user can then activate MMS or video call with the car unit. In Fig. 2(b), we demonstrate a burglarproof application. When a potential burglar event is detected (such as doors being opened), VS^3 will send the owner a short message. Since an immediate action is needed, VS^3 will directly record a video clip and send it to the owner via MMS. More importantly, the video clip is a critical clue and evidence in a lawsuit.

In the tracking part, Fig. 2(c) shows a surveillance scenario. Through its camera, VS^3 will continuously take snapshots on neighboring vehicles. VS^3 will retrieve these license plate numbers and compare them against a database of suspicious plate numbers provided by the police department (through the Internet or nearby police cars). When a suspicious vehicle is identified, the on-board unit can transmit a report message to the police department via 3G networks. The police department then can take further actions. In addition, the on-board unit can broadcast this message to neighboring vehicles by vehicle-to-vehicle (V2V) communications (through IEEE 802.11p [1] interfaces). Thus, the traces of suspicious vehicles can be continuously logged, which are valuable clues to the police department. This brings up a new challenge of how to conduct cooperative tracking by general vehicles on the street.

3. PROTOTYPE IMPLEMENTATION

We have developed a prototype of VS^3. The microprocessor in the car unit is an ARM9 Mini2440 [2] with a 3.5” TFT LCD, as shown in Fig. 3(a). It is equipped with a CAM130 camera, which has a 400MHz 32-bit RISC integer processor (ARM920T [3]), 64MB SDRAM, 64MB Nand Flash, Camera Interface, three serial ports, and a 10/100M Ethernet RJ-45. Mini 2440 can issue snapshot commands to

Figure 4: Prototyping demonstration.

CAM130 for taking full-resolution pictures. To output the captured video data to an image file, the jpeg library, *libjpeg*, is linked to the executable program. The CO_2 module is a H-550EV CO_2 sensor [4] integrated with Jennic JN5139 [5] as shown in Fig. 3(b), which has 0∼5,000 ppm measurement range and ±30 ppm accuracy. The 3G module is the Wavecom Q2403A GSM/GPRS/CDMA module as shown in Fig. 3(c), which is controlled by Mini2440 via AT commands. The GPS module is implemented by uPatch300 [6], as shown in Fig. 3(d), which follows the NMEA (National Marine Electronics Association) 0183 protocol.

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 car security, we demonstrate a door-trigger scenario as shown in Fig. 4(a) and a CO_2-monitoring scenario in a model car as shown in Fig. 4(b). For car tracking demonstrations, Fig. 4(c) and Fig. 4(d) show our prototyping system set up in a real car and a suspicious vehicle tracking scenario, respectively.

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An Implementation of a Vehicular Surveillance and Sensing System for Car Security Applications

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***Abstract*—In this paper, we propose a *Vehicular Surveillance and Sensing System* (VS^3), which targets at car security applications. On the car side, it consists of a sensing module, a surveillance module, a communication module, and a control module with a microprocessor. On the user side, when he/she leaves the car, only a 3G mobile phone is needed. VS^3 can be triggered by events detected on car, such as abnormal air quality, unusual sound frequencies, and potential burglary. Via a 3G module, a user can have multimedia communications with the car unit. Application scenarios include detecting an abnormal CO_2 level, unusual sound frequencies, or potential car burglary, which triggers VS^3 to transmit SMS, MMS, or interactive video calls to the vehicle owner, who can then monitor the car situation. This paper demonstrates our current prototype.**

Keywords: Burglarproof, IEEE 802.15.4, Surveillance, Vehicular Sensor Network, Wireless Network.

I. Introduction

The rapid development of micro-sensing MEMS and wireless communication technologies has made *vehicular sensor networks* (VSNs) possible. In a VSN, a number of sensors are placed on vehicles to collect environment data and these sensed data can be utilized for various purposes, such as vehicle tracking [2], crash prevention [3], environment monitoring [7], and mobile surveillance [8].

On the other hand, 3G/3.5G mobile systems are fast developing and widely deployed. This would greatly enrich the interaction between users and VSNs. For example, a burglarproof system can provide video calls between a user and the on-board unit. As another example, traditional surveillance systems for vehicle monitoring rely on roadside cameras for video recording. It requires huge efforts to distinguish targets from many other candidates and also a lot of labors to go through these videos. With 3G/3.5G systems, such video-recording work can be done in an on-demand manner via on-street vehicles.

In this work, we propose a 3G-enhanced VSN called *vehicular surveillance and sensing system* (VS^3). On the user side, only a 3G mobile phone is needed. On the car side, the on-board unit consists of a sensing module (such as CO_2 sensor and microphone), a surveillance module (such as a camera and some recognition software), a communication module (such as 3G and WAVE/DSRC), and a control module with a microprocessor. The microprocessor is responsible for issuing commands and coordinating with other modules. VS^3 can be triggered by events detected by the car. We will show how events of abnormal air quality, unusual sound frequencies, and potential burglary can be exploited. This allows the surveillance module to be activated in an on-demand manner. Thus, VS^3 can avoid recording unnecessary videos when nothing happens. Alternatively, for simpler events, VS^3 can transmit SMS (short message service) or MMS (multimedia message service) to the vehicle owner, who can then decide whether to initiate a video call. This paper demonstrates our current prototype.

II. System Architecture and Applications

Fig. 1 shows the VS^3 architecture. On the car side, it consists of the following components: a CO_2 sensor for detecting the CO_2 level inside vehicle, a microphone for detecting unusual sound frequencies inside vehicle, a camera module for taking photos or recording videos inside the car, a 3G module for transmitting SMS, MMS, or interactive video calls, and a microprocessor for controlling all these components. On the user side, only a 3G mobile phone is needed to receive warning

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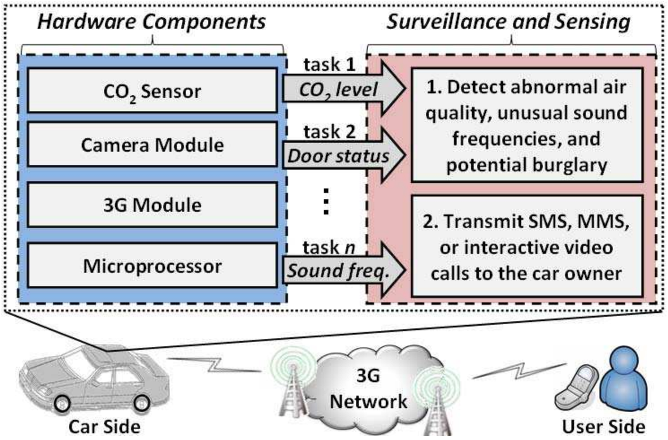

Fig. 1. System architecture of VS^3.

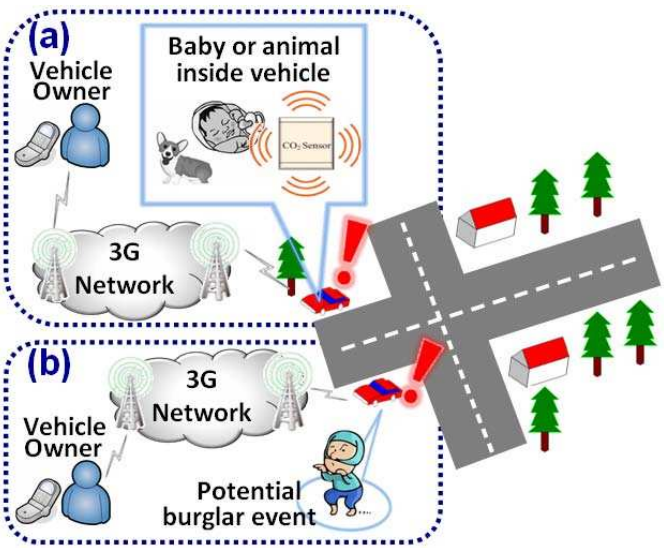

Fig. 3. Car security and burglarproof applications.

short messages, pictures or video clips inside the vehicle, and interactive video calls. To illustrate how VS^3 works, we demonstrate a car security and a car burglarproof applications below. Fig. 2 shows the VS^3 flowchart.

A. Car Security Application

In Fig. 3(a), after the driver parks the vehicle and activates the car unit, VS^3 will continuously check the CO_2 concentration in the vehicle for a predefined period. During this period, if there is no abnormal CO_2 concentration, it implies there is no baby or animal in the car. So the CO_2 sensor can be shut down for power-saving. Otherwise, when it is found that the CO_2 concentration is beyond a dangerous threshold, VS^3 will send a short message to notify the predefined phone number (user unit). On receipt of the warning message, the owner

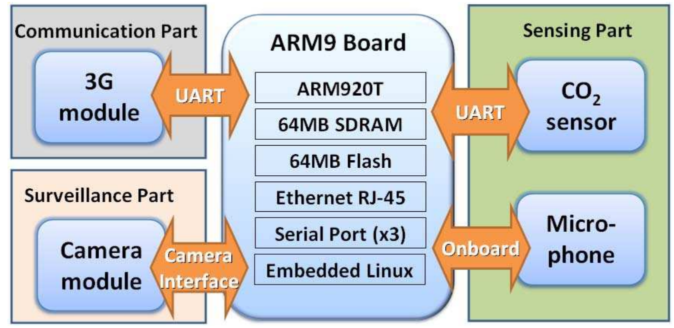

Fig. 4. Building blocks of the car unit.

can return a command short message to VS^3. According to the command, VS^3 activates the camera module and initiates a video call to the owner. Through the live video call, the user can monitor possible abnormal events (such as baby or animal forgotten in the vehicle) by his/her 3G phone. Thus, loss of lives can be avoided.

B. Car Burglarproof Application

In Fig. 3(b), VS^3 notifies the owner via SMS as a potential burglar event is detected (such as doors being opened). Since an immediate action is needed, VS^3 will directly record a video clip and send it to the owner via MMS. More importantly, the video clip is a critical clue and evidence in a lawsuit.

III. Prototype Implementation

We have developed a prototype of the proposed car unit. Fig. 4 shows its building blocks. There is an on-board microphone on the control module (the red circle in Fig. 5). The camera module is connected to the microprocessor via build-in Camera Interface, whereas the other modules are mounted through the UART interfaces. Below, we describe implementation details.

A. Microprocessor

The microprocessor in the car unit is an ARM9 board (Mini2440 [4]) with a 3.5" TFT LCD as shown in Fig. 6, which has a 400MHz 32-bit RISC integer processor (ARM920T [1]), 64MB SDRAM, 64MB Nand Flash, Camera Interface, three serial ports, and a 10/100M Ethernet RJ-45. 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.

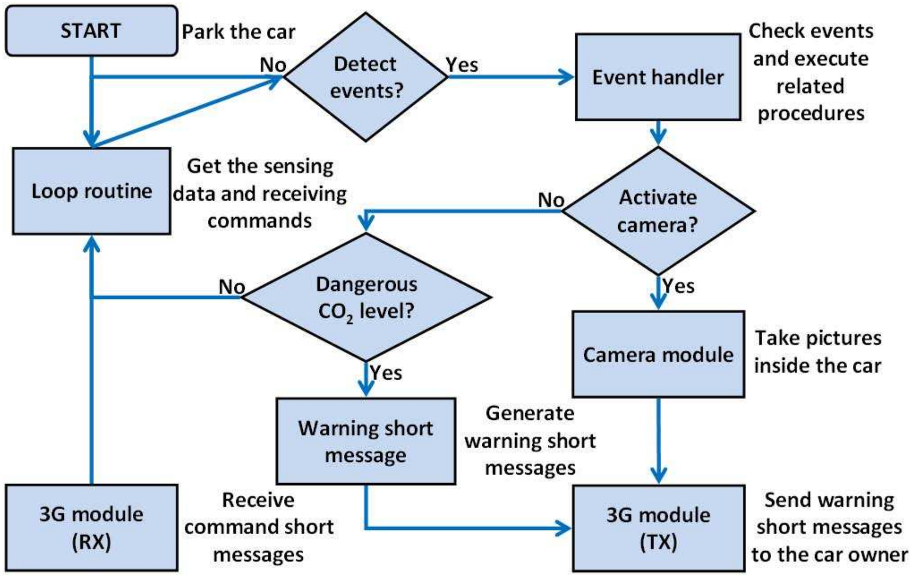

Fig. 2. Flowchart of VS[3].

Fig. 5. Control module with an on-board microphone.

Fig. 6. Mini2440 development board with a 3.5" TFT LCD.

B. CO_2 Sensor

The CO_2 module has a H-550EV CO_2 sensor [5] integrated with Jennic JN5139 [6], which is mounted to Mini2440 via an UART interface. Our prototype is shown in Fig. 7. The CO_2 sensor module has 0$\sim$5,000ppm measurement range and $\pm$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.

C. 3G Module

We adopt the Wavecom Q2403A GSM/GPRS/CDMA module as shown in Fig. 8, which is controlled by Mini2440 via AT commands. It performs SMS, MMS, and video calls as instructed by the ARM9 board. To

Fig. 7. H-550EV CO_2 sensor integrated with JN5139.

Fig. 8. Wavecom Q2403A module.

send a short message, AT commands are issued to control GSM/GPRS modem.

D. Camera Module

Fig. 9 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

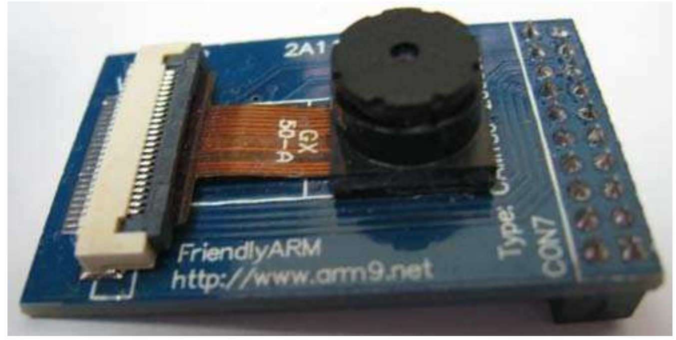

Fig. 9. CAM130 camera module.

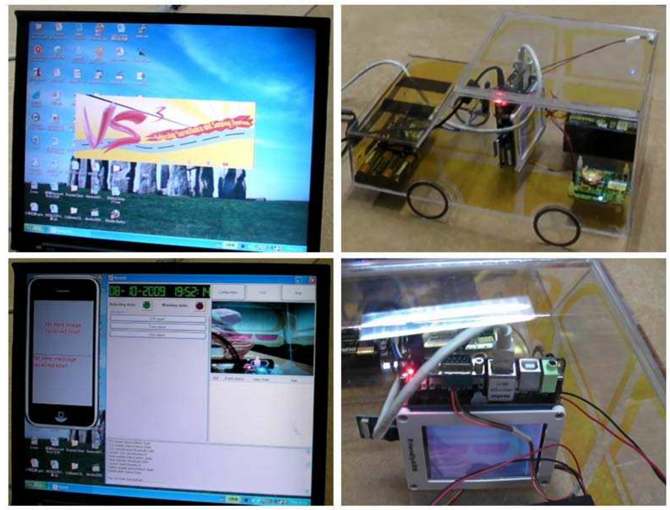

Fig. 10. VS^3 prototyping system.

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.

E. Demostration

Fig. 10 shows the VS^3 prototype in a model car and the graphical user interface (GUI) in the laptop computer. The demo video of VS^3 can be found in http://www.cs.nctu.edu.tw/∼lwchen/VS3.avi. In the bur-

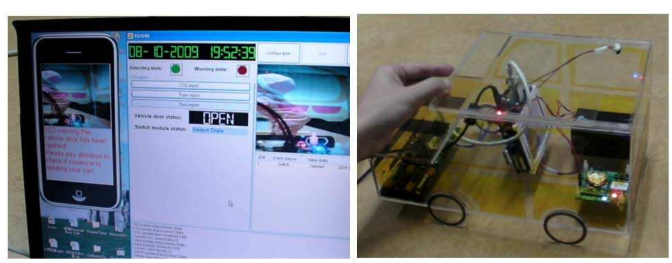

Fig. 11. Burglar door open detected by VS^3.

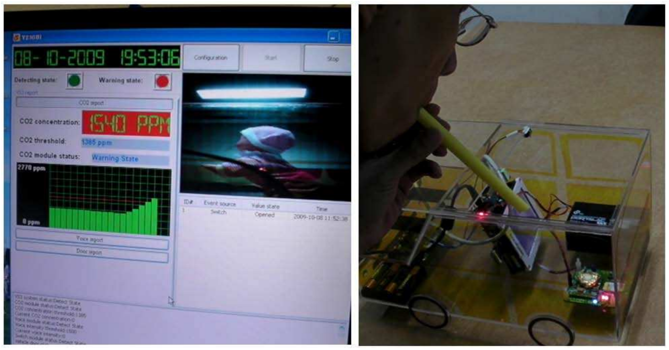

Fig. 12. Abnormal CO_2 level detected by VS^3.

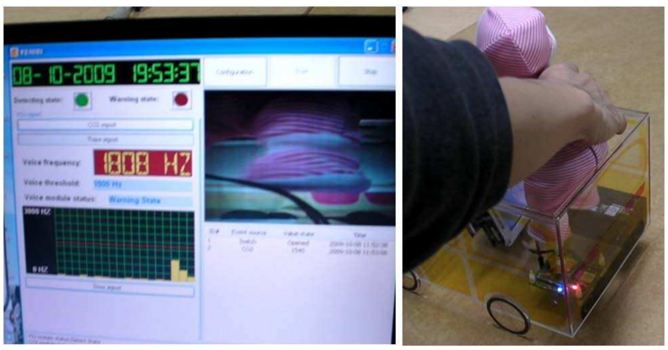

Fig. 13. Unusual sound frequencies detected by VS^3.

glarproof application, after the car is parked on the road, if the car door is opened by someone without deactivate the VS^3 alarming, it implies that there is some thief stealing the car. In Fig. 11, we open the skylight of the model car for simulating the car door is opened during the VS^3 alarming. The GUI shows the car door is opened and thus triggers VS^3 to transmit a warning short message to the vehicle owner as shown in Fig. 14(a).

In the CO_2 monitoring application, the concentration threshold is set to 1500ppm. In Fig. 12, we blow some CO_2 gas to the CO_2 sensor through a straw for simulating there is some baby or animal left in the car. The GUI shows the CO_2 level inside the model car is more than the predefined threshold and thus triggers VS^3 to transmit a warning short message to the vehicle owner as shown in Fig. 14(b).

(a) (b) (c)

Fig. 14. Warning short messages sent by VS^3.

Before the CO_2 level is more than the predefined threshold, the on-board microphone of Mini2440 is also used to detect unusual sound frequencies inside the car, which represents the baby or animal left in the car is crying or screaming, In Fig. 13, we use a baby doll screaming inside the model car for simulating there is a baby left in a parked car. The GUI shows the sound frequency inside the model car is higher than the predefined threshold (1500 Hz) and thus triggers VS^3 to transmit a warning short message to the vehicle owner as shown in Fig. 14(c).

IV. Conclusion

VS^3 integrates 3G communication and CO_2 sensing into surveillance technologies to support intelligent car security applications. The vehicle owner can be informed immediately as unusual events are detected on car. At the same time, the owner can remotely monitor the situation inside vehicle and then take proper actions if necessary. VS^3 can prevent vehicles form burglar or keep evidences to catch the thief. Furthermore, The baby or animal forgetfully left in the vehicle can be rescued in time by the assistance of VS^3. The future extension of VS^3 could be equipped more various sensors and form a VS^3 network to investigate cooperation issues and develop novel applications.

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Efficient Data Collection and Distribution in Two-tier Vehicular Long-thin Networks

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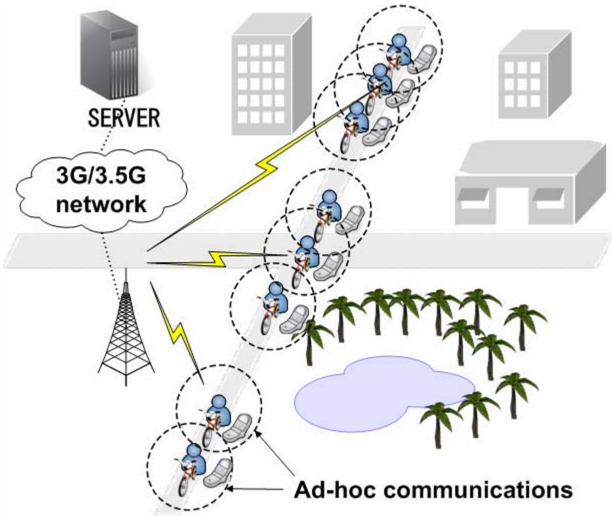
Abstract

This paper investigates the optimization of data collection and distribution in two-tier vehicular long-thin networks (VLTNs). The fleet of bikers using smart phones with the common cycling path forms two-tier VLTNs, which consist of a 3G/3.5G high-tier interface and an IEEE 802.11-based low-tier interface. In a cycling fleet, it causes insufficient bandwidth and long delay problems as all bikers upload their data and download the fleet information via 3G/3.5G communications. To reduce the bandwidth usage and the transmission delay of 3G/3.5G communications, we propose a framework consisted of a dynamic grouping mechanism and a group maintenance scheme. In the proposed framework, bikers belonging to the same group exchange data with each other via ad-hoc communications and only the group leader needs to report the group member data and obtain the fleet information to/from the server via 3G/3.5G communications. Then, the group leader employs ad-hoc communications to broadcast the fleet information to all other members. Through the cooperation between 3G/3.5G and ad-hoc communications, the high-tier bandwidth cost and transmission delay can be minimized. Simulation results show our framework outperforms existing works that significantly reduce the amount of 3G/3.5G data and the number of 3G/3.5G connections. In addition, we use smart phones to implement a Google Android and Maps-based prototype for cycling fleet communications.

1. Introduction

近年來，愛好自行車騎乘活動的人士與日俱增，不論在通勤、運動、或娛樂方面均有越來越受歡迎的趨勢。另外一方面，由於高油價時代的來臨，人們逐漸以自行車取代汽車作為上班的通勤工具。除了通勤之外，人們更於週末假日在郊外騎自行車以達到運動或踏青的目的，相關文獻包括建置公共自行車租用系統[1]、設計電動自行車系統[2]、以及實作自行車感測器系統[3]等。在本篇論文中，我們探討在雙層式網路架構下之自行車車隊通訊效能最佳化的問題，自行車車隊網路因具有共同騎乘路線而形成一個長鏈狀的車載網路，其上層網路介面為3G/3.5G，下層為IEEE 802.11 Ad-hoc網路，圖一顯示具有三個Ad-hoc通訊群組的自行車車隊網路。



圖一、自行車車隊網路架構

在移動式無線隨意網路(Mobile Ad Hoc Network, MANET)的研究領域中，針對群組成員通訊的群播(Multicast)方法主要可分為三大類，第一類為樹狀群播法(Tree-based) [4]-[8]，每個群組都需建立一個群播樹來負責成員間的通訊；第二類為網狀群播法(Mesh-based) [9][10]，每個群組都需建立一個網狀拓樸來轉送成員間的資料；第三類為雙層式群播法[11]-[18]，每個群組都需建立一個骨幹拓樸來傳遞成員間的資料。

雖然樹狀群播法較易實作，但是在靠近根節點處(Root Node)卻容易造成傳輸瓶頸，另外，當有非末端節點(Intermediate Node)故障時，群組中某些成員便無法與根節點保持通訊。而網狀群播法可藉由氾濫式廣播(Flooding)將資料傳送至所有鄰居節點來提供較佳的連通性，然而卻需消耗較多的頻寬，而且在有新成員加入群組時，會造成整個網路的訊息氾濫式廣播。這種方式在大型移動式無線隨意網路中可說是一種非常耗時和浪費頻寬的方式。為了避免進行整個網路的氾濫式廣播動作，雙層式架構的群播方法陸續在大型移動式無線隨意網路中被提出，群組中部份成員將被選作骨幹節點，專門負責管理群組拓樸以及決定傳

輸路徑，並將氾濫式廣播的動作限制在骨幹節點之間，然而，這些在移動式無線隨意網路所提出的方法並未針對具有共同騎乘路線之自行車車隊網路特性來設計，例如網路拓樸為長鍊狀、網路中每個節點具有類似的移動行為…等等。

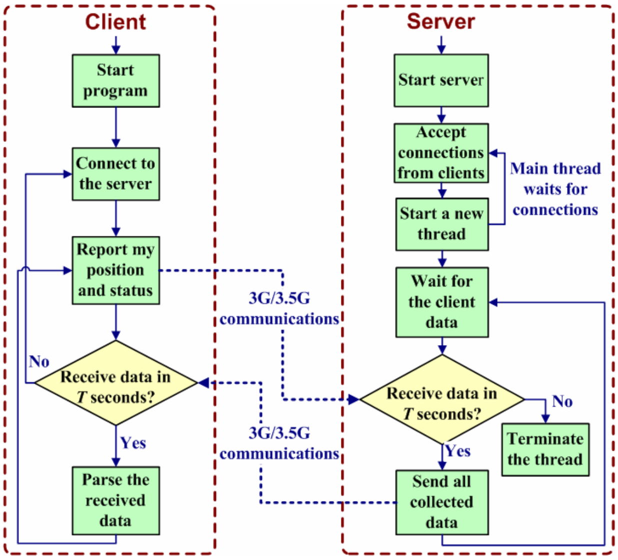
在本篇論文中，我們將針對自行車車隊網路的特性來著手研究其通訊效能最佳化之問題，並且實作出一套車隊通訊與管理系統，實作系統將利用Android智慧型手機作為使用者手持裝置，並解決網路更新位置資訊的問題。在雙層式網路架構中，我們建構一個Server來達到資訊交換的目的，使用者向Server端更新資料，再去下載所有人目前的資訊並顯示在螢幕畫面中，透過這樣的架構，我們達成在Android智慧型手機的Google Map上，可以經由3G/3.5G網路看到所有人的狀態與位置。

然而，此一自行車車隊架構存在以下的問題，若使用3G/3.5G網路的使用者過多，則會造成3G/3.5G網路的負擔、延遲較嚴重的問題。此外，由於所有人都需要跟伺服器更新及下載資料，倘若完全都由一個人負責與伺服器通訊，一旦成員太多，則會形成整個網路的傳輸瓶頸(Bottleneck)，因此，必須要替整個車隊成員做分群來分散整個網路通訊負擔。

分群完畢後必須要收集與散佈車隊成員位置與狀態資料，故群組Gateway的選擇也是非常重要的議題，選擇到不適當的成員作為群組Gateway會造成傳輸延遲變大、封包的碰撞嚴重。本篇論文的目的是利用雙層式網路架構來達到資料收集及散佈之功能，如此一來即使離開車隊太遠的成員，也可以隨時利用3G/3.5G網路來保持聯繫，靠近車隊時便可以利用Ad-hoc通訊以減少3G/3.5G網路封包傳輸量。

2. System Design

圖二為我們所設計之自行車車隊群組Gateway與Server之間的通訊流程，目標為在整個車隊環境的網路架構下，每個使用者都可以達到快速且正確的獲得整個車隊的資訊並將資料更新到伺服器端，因此接下來將針對整個網路架構提出幾點解決方案：(1)降低3G/3.5G網路的負荷量：倘若所有使用者各自跟伺服器端更新資料，則會造成整個3G/3.5G網路的負荷量過大以及整體延遲過長的問題，在此機制中，我們提出了雙層式架構來降低3G/3.5G網路的負擔，解決方法為尋找一個適當群組Gateway作為替群組成員向伺服器更新下載資料的主要出口，如此一來一個群組只需要一個人負責更新和傳遞資料即可。(2)在合理的延遲下降低Low-tier的封包碰撞程度：在使用者要傳遞資料給群組Gateway時，倘若沒有一個適當的順序，則會導致封包碰撞問題嚴重且更新的效率不佳，因此我們提出了一個在Long-thin網路架構下的路由機制，此機制有如接力比賽一般，即所有使用者依序向下更新資料，依序整合之前的資料並傳下給一個人，如此可以減少資料的更新次數並降低封包碰撞率。(3)提供使用者端自動加入/離開群組來節省3G/3.5G網路的花費：在整個網路架構下，使用者勢必會因為身在位置不同，而被判定為身在哪一群組，並由不同的模



圖二、自行車車隊網路通訊流程

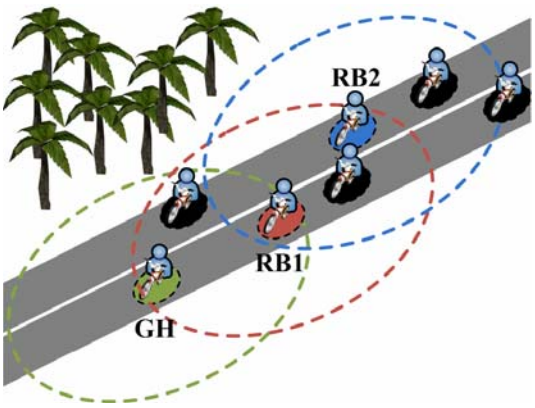
式來下載及上傳資料，因此我們希望可以自動替使用者節省3G/3.5G網路的花費而不需要使用者做任何的操作。

給定一個自行車車隊成員網路G(V, E)，車隊成員為端點v ∊ V，若兩車隊成員在彼此Low-tier通訊範圍內，則此車隊成員間存在一連通線e ∊ E，依序將連通的點加入集合中，直到沒有點可以再加入，則這些點即為一個連通圖(Connected Graph)，如此可將車隊成員網路形成一個一個的連通圖。定義一個Long-thin群由一個Gateway端點以及若干個成員端點組成，同一Long-thin群成員可用Low-tier通訊來交換彼此的位置資訊，Gateway使用Low-tier通訊收集完所有成員端點的位置資訊後，便使用High-tier通訊回報給Server，Server收集完所有Long-thin群的位置資訊後，便使用High-tier通訊回傳給各Long-thin群的Gateway，各Gateway再以Low-tier通訊回傳給Long-thin群內的所有成員，以下是我們所設計之通訊協定的目標：

- 分群機制(Grouping)：根據延遲限制(Delay Bound)決定一個Long-thin群的大小
- 3G/3.5G通訊效率(High-tier Efficiency)：針對每一個Long-thin群決定其上傳及下載可節省最多High-tier頻寬的Gateway
- 資料繞徑(Routing)：針對每一個Long-thin群成員決定最佳繞徑路由至Gateway以獲得最大的頻譜再使用(Spectral Reuse)效率
- 傳輸排程(Scheduling)：針對每一個Long-thin群成員決定最佳傳輸排程以減少封包碰撞機率與封包傳輸延遲
- 資料減量(Data Aggregation)：針對每一個Long-thin群成員所傳輸的位置資訊封包進行Aggregation以減少封包傳輸量

3. The Proposed Framework

3.1. 動態分群機制



圖三、自行車車隊網路群組

首先定義同一個群組的車隊成員必須是朝同方向行進且可經由Ad-hoc通訊方式傳遞資料給其他成員。然而，對於同一個群組中的成員個數必須加以限制，因為倘若成員個數太多，將會造成資料收集與散佈之時間過長的問題，假設ω為車隊成員個數最大值。

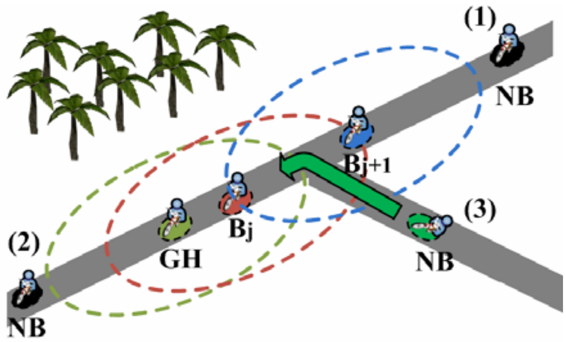
圖三為一個形成車隊群組的例子，其中每台自行車必須扮演Group Header (GH)或Group Member (GM)其中之一的角色，且每台自行車Bi會有一個屬於自己的Serial Number (SNi)，此SNi對於每台自行車在群組中是唯一的數值。倘若該自行車扮演GH的角色，則必須週期性的廣播Invitation Advertisement Beacon (IAB)，圖四為IAB封包的格式定義，包含了Beacon Type為訊息種類，Heading Direction為群組行進的方向、Coordinate為Source目前所在的座標、Current Serial Number (SNc)為目前已使用的最大SN(即目前群組內車隊成員的數量)、Source SN (SNs)為IAB發送者的SN。週期性發送IAB的主要目的是通知不在群組內卻靠近到整個群組之通訊範圍的自行車成員，若此群組尚未達到車隊成員個數最大值，則此接近之自行車將被允許加入群組，反之則否。

Integer	(X，Y，Z)	(X，Y)	Integer	Integer
Beacon Type	Heading Direction	Coordinate	Current Serial Number	Source SN

圖四、Invitation Advertisement Beacon封包格式定義

GM必須協助Relay由GH發出的IAB，Relay的方式是以越遠收到的GM，則具有越小的Backoff Timer為基礎，因此收到IAB且距離Source最遠的自行車將會因Backoff Timer最小而優先Relay，在此稱為Relay Bike 1 (RB1)，而Relayed IAB中的Heading Direction，Coordinate，與Source SN皆必須分別更新為RB1的行進方向、RB1目前所在的座標，與RB1的SN。而介於GH和RB1之間的自行車則因為收到具有相同SNc的IAB則不再協助Relay IAB。同理，在RB1廣播出去之後，RB1後方的車輛也必須協助RB1作Relay IAB的動作，相對距離RB1最遠的車輛為RB2，則RB2優先Relay IAB，一直做到無人Relay即自動結束。

假設θ值為一段時間區間，當一台自行車New Bike (NB)剛啟動車上通訊裝置時，必須先等待θ的時間，倘若這段時間內沒有收到來自其它群組的IAB，則自己形成一個新的群組，且自己就是GH。倘若有收到，



圖五、New Bike判斷是否加入群組

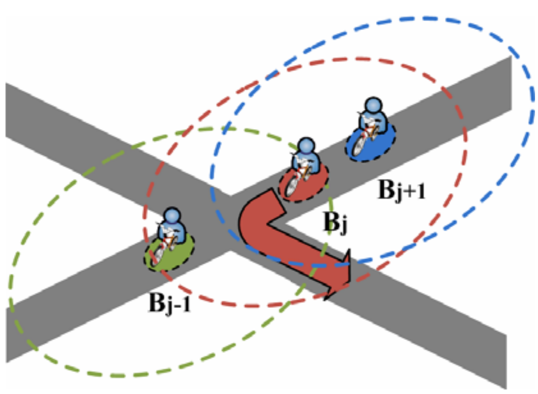
則必須針對IAB內容判斷自己是否要加入，判斷機制如下所述：

首先NB判斷行進方向是否相同，倘若方向不同，則不予理會且繼續等待直到θ結束。倘若方向相同，如圖五所示，則分成(1)收到的IAB來自於最後一台車，即SNs = SNc、(2)收到的IAB來自於GH，即SNs = 1、(3)收到的IAB來自於中間協助Relay之RB，即1 < SNs < SNc。

在(1)的狀況下，即SNs = SNc，代表NB是由最後方加入，則NB直接設定自己的SN為SNc+1，並且回傳訊息通知GH多了一名新的成員。而在(2)的狀況下，即SNs = 1，代表車輛是由前方加入，則情況類似(1)，設定自己的SN為1成為新的GH，並且回傳訊息通知舊的GH，舊的GH再以越遠收到的GM，則具有越小的Backoff Timer的廣播機制通知群組內所有車輛將自己的SN加1。而在(3)的狀況下，即1 < SNs < SNc，代表收到的IAB來自於中間協助Relay之RB，代表NB是由其他路線轉向而來並且出現在群組的中間，則此時NB加入群組中並發出訊息要求範圍內的前後方成員回傳IAB，且回傳的IAB等待的Backoff Timer以距離越近越先傳送為基礎，IAB內容必須包含位置資訊與SNs，當收到的SNs為SNi與SNi+1，則NB設定自己的SN為SNi+1，並通知後方之成員車輛將自己的SN加1。

3.2. 群組合併與分離機制

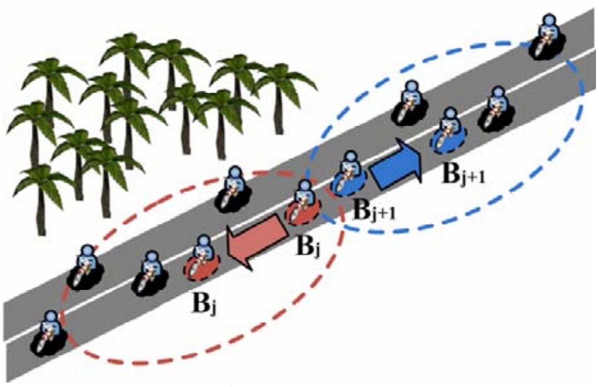
前面所述為新成員如何加入群組的機制，而在群組與群組之間，或是群組內也有許多情況造成群組成員的變動，其原因可分成以下三種：(1)圖六顯示群組中自行車Bj轉到別的方向行駛，而離開原本Bj所在的群



圖六、Bj轉彎而導致群組無法傳遞位置資訊與更新SN

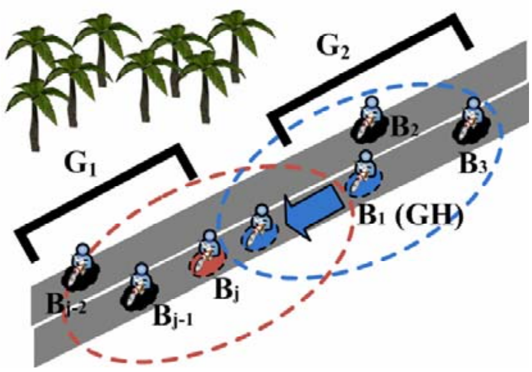
組，並導致中間連結斷開。(2)圖七顯示原本在群組內的Bj因為速度加快或是與之後的車輛速度一起減慢導致逐漸遠離Bj傳輸範圍，導致中間連結斷開。(3)圖八顯示原本分屬兩個群組的自行車，後方的G_2往前追上前方G_1而形成同一個群組。

在(1)的情況中，原先群組中的前後車輛皆在傳輸範圍之內，倘若其中有一台車輛Bj轉向而離開傳輸範圍，導致要將位置資訊往下一台車輛傳遞時無法成功，由於原本Bj收到位置資訊後會再廣播給後方車輛，倘若後方車輛沒有收到來自Bj的位置資訊，則偵測到Bj不在傳輸範圍內，因此即自行形成新的GH，並發出訊息讓後方車輛SN都各自減j，經過此程序而形成新的群組。



圖七、Bj改變速度導致群組成員無法傳遞位置資訊

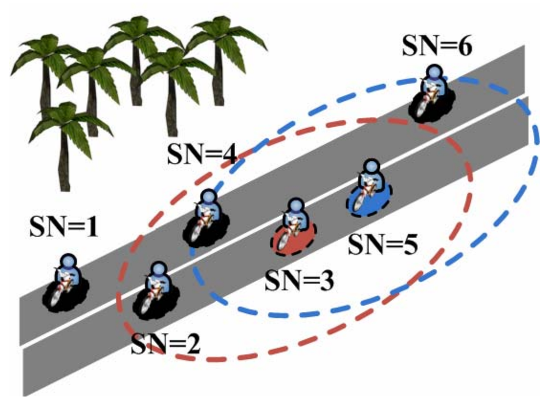
而在(2)的情況中，其實與(1)類似，當速度減慢，距離Bj越來越遠，直到超出Bj傳輸範圍，或是Bj速度加快，直到超出Bj傳輸範圍，同樣會收不到Bj廣播給後方的位置資訊，因此也自行形成新的GH，並發出訊息讓後方車輛SN都各自減j，經過此程序而形成新的群組。



圖八、G_2逐漸追上G_1導致兩個群組合併成為一個群組

在(3)的情況為原先兩個獨立的群組形成一個新群組，在後方的G_2由於往前加速追上G_1，或在前方的G_1速度減慢被G_2追上，則G_2的GH會聽到G_1所發出的IAB，則G_2判斷行進方向是否與G_1相同，若相同則加入G_1形成同一個群組，同時也必須通知G_2的群組成員將自己的SN加上G_1的SNc。

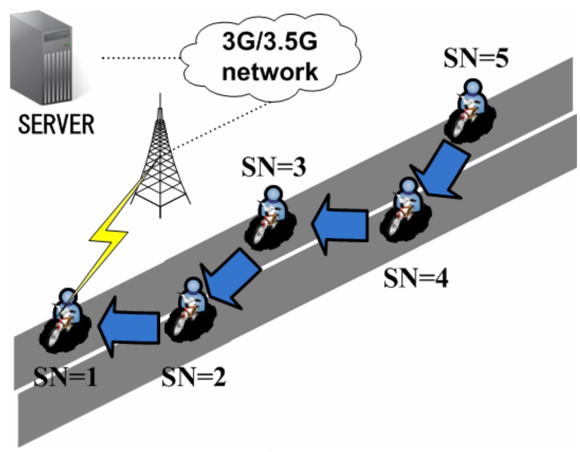
3.3. 傳輸順序維護機制



圖九、傳輸範圍內的小幅順序錯亂情況

在整個自行車車隊群組的騎乘過程中，除了大幅的變動導致中間無人傳遞資訊之外，如圖九所示，也有可能因為車輛加速減速的情形而會有小幅的變動，導致SN錯亂，並沒有依照正確的方式排序，但卻不影響位置更新的情況，除了在傳遞位置資訊時可以偵測到前一車輛是否還在傳輸範圍內的大幅變動的情形，同時我們也希望可以更主動的維持整個群組中SN的正確性，以減少可能會發生的無人續傳位置資訊的狀況，因此，我們進一步設計出了兩個方式去主動地檢查目前的群組成員的SN是否正確。

第一個方法如圖十所示，當所有使用者將位置資訊逐次上傳到GH之後，則GH會擁有所有車輛的位置資訊，再由GH根據所收集的位置資訊，決定新的位置資訊並以廣播的方式傳送給群組中成員。第二個方法是要依順序上傳位置資訊之前，由GH廣播一個Reordering Beacon (ROB)通知要重建SN，ROB中包含目前所設定到的SN(目前為1)，而越近的成員越先收到就立刻Relay此ROB，設定自己的SN為ROB中的SNs加1，直到最後無人Relay為止，則所有車輛就有最新的SN資訊。



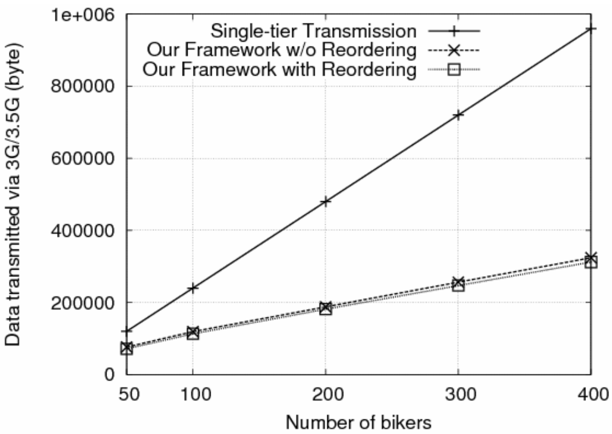
圖十、GH計算各個車輛的新SN

如此一來，整個自行車車隊可動態地形成各個群組，並具備最新的SN資訊，各個群組內的車隊成員根據自己的SN依序(SNc, SNc-1,...,1)將位置資訊以相對經緯度位置代替絕對經緯度位置Aggregate後用

Ad-hoc通訊方式傳遞至GH，然後GH將整個群組Aggregated的位置資訊回傳至Server，Server收到各個群組的位置資訊後，再將整個自行車車隊網路的位置資訊傳送給各個GH，而GH收到後再以相反的順序(1, 2,..., SNc)傳送給群組內所有的車隊成員。

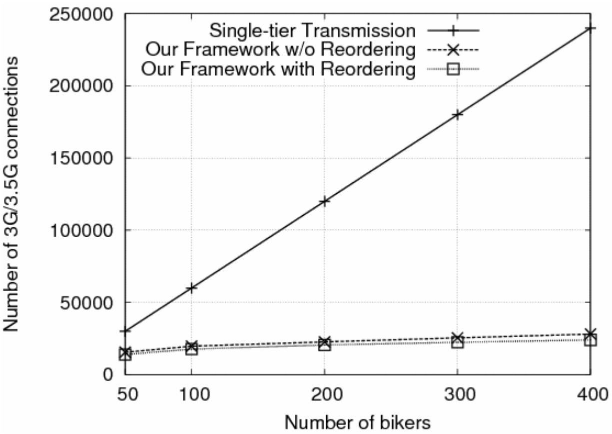
4. Performance Evaluation

在本節中，我們使用Java模擬器來實驗Single-tier資料收集與散佈機制以及本篇論文所設計的高效率資料收集與散佈機制所需要傳輸之3G/3.5G資料量與建立之3G/3.5G連線數，整個車隊網路的總Biker數設定為50、100、200、300、與400，每秒更新一次位置資訊，每次模擬實驗的時間為600秒，每個數值為100次模擬實驗的平均值。圖十一和圖十二顯示在不同Biker數的情況下，各機制的3G/3.5G資料傳輸量以及3G/3.5G連線建立數。



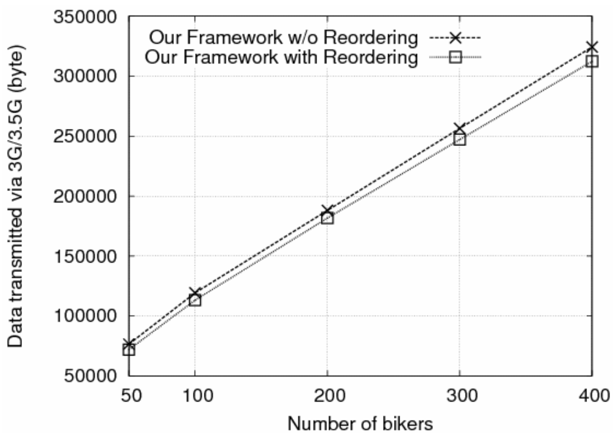
圖十一、3G/3.5G資料傳輸量之效能比較

圖十一顯示當Biker數增加時，所需要傳輸之3G/3.5G資料量則是上升的。對於Single-tier機制而言，由於所有Biker都是透過3G/3.5G連線來傳輸其資料而使得所需要傳輸之3G/3.5G資料量快速地上升；我們所設計的高效率資料收集與散佈機制則有著較低的3G/3.5G傳輸需求，而且當Biker數越大時，我們的資料收集與散佈機制所需要之3G/3.5G傳輸量只有Single-tier機制的三分之一。



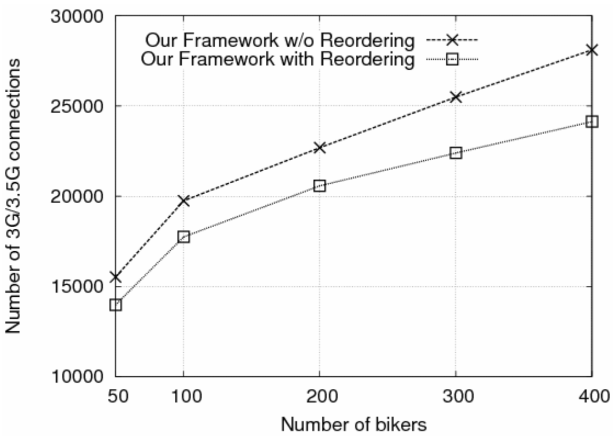
圖十二、3G/3.5G連線建立數之效能比較

圖十二顯示在不同Biker數的情況下，各機制造成的3G/3.5G連線建立數。其結果顯示Single-tier機制在Biker數增加時，其3G/3.5G連線建立數呈現指數性的增加；而我們所設計之高效率資料收集與散佈機制在Biker增加時，其3G/3.5G連線建立數只呈現線性的成長。在圖十二的結果中，Single-tier機制由於其指數成長的3G/3.5G連線建立數，使得其資料傳輸延遲將遠高於我們的機制。我們的機制由於能夠將Biker分群並使用Ad-hoc通訊將資料透過Gateway統一發送給Server，而使得其3G/3.5G連線建立數可降至最低。



圖十三、維護傳輸順序對資料傳輸量之效能影響

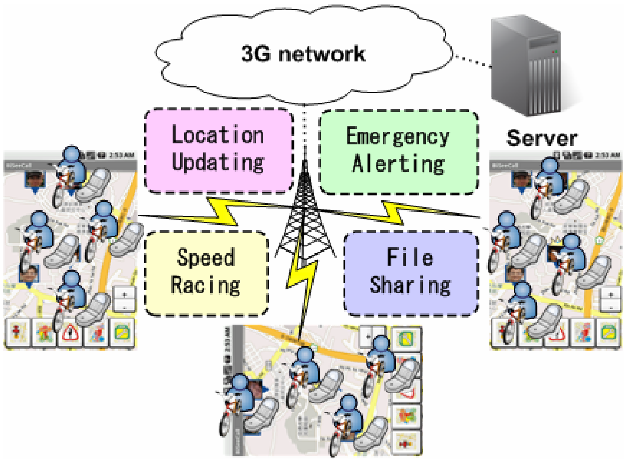
圖十三與圖十四分別顯示我們所設計之高效率資料收集與散佈機制在持續維護傳輸順序之後，對於3G/3.5G傳輸需求與連線建立數的效能改進幅度。這是因為當傳輸順序未保持在最新的狀態時，GM的位置超前GH之後，便會可能形成新的群組而造成3G/3.5G資料傳輸量與連線建立數增加的情況。



圖十四、維護傳輸順序對連線建立數之效能影響

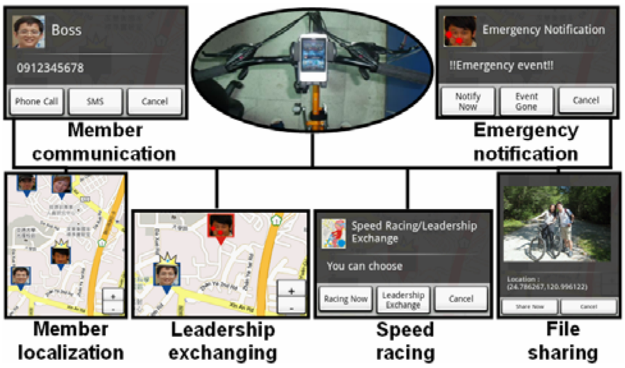
從圖十一至圖十四可知我們所設計之高效率資料收集與散佈機制具有較低的3G/3.5G傳輸需求以及較低的3G/3.5G連線建立數，換言之，在長鏈狀車載網路中採用我們的機制可有效地預防3G/3.5G基地台因頻寬不足，而造成資料傳輸的嚴重延遲，以及避免所有Biker都建立3G/3.5G連線，而造成不必要的花費。

5. Prototype Implementation



圖十五、實作系統通訊架構

在本節中，我們設計並實作出一套車隊通訊與管理系統，利用Android智慧型手機作為使用者手持裝置，可有效地達成車隊成員更新位置與狀態資訊的目的。車隊網路通訊系統架構如圖十五所示，使用者透過智慧型手機所提供的3G/3.5G與WiFi通訊能力，建構出雙層式的車隊網路，彼此在下層網路通訊範圍的成員可藉由Ad-hoc通訊來交換各自的位置與狀態，距離過遠的成員則可透過上層網路的3G/3.5G通訊向Server來取得彼此之資訊。此外，每個Ad-hoc群組具有一個Gateway來負責將整個群組的位置與狀態傳遞給Sever彙整，Server會定時將收集到的車隊成員資料傳遞給每一個Gateway，如此一來，上層網路的3G/3.5G通訊就可大量減少，3G/3.5G的頻寬消耗與傳輸延遲便可獲得有效的控制。



圖十六、Android 車隊通訊與管理系統功能

圖十六顯示車隊通訊與管理系統主要功能：(1)車隊定位(Member Localization)：可即時取得車隊成員現在的位置，與其他人分享。若有隊友脫隊，會在手機上顯示警示符號。透過點選隊友圖示可顯示其個人資訊及位置，並可直接進行車隊通訊；(2)車隊通訊(Member Communication)：使用者可透過點選地圖上成員的圖示，以取得隊友的狀態或與隊友通訊，透過網路可與隊友進行語音/視訊電話、簡訊、以及群組即時通訊；(3)緊急通報(Emergency Notification)：若是在路程中發生交通意外，可以使用緊急通報，讓隊友知道自己現在的情況；(4)隊長更換(Leadership Exchanging)：使用者可藉由點選特定符號以告知車隊成員，其有意願當車隊長，或是車隊長希望交棒給其他車隊成員；(5)車隊競賽(Speed Racing)：隊長可利用車隊競賽功能發出競賽通知，隊員接獲通知可立即前往集合地點，一同開始往競賽終點衝刺；(6)檔案共享(File Sharing)：使用者可將騎乘路程中所拍攝的照片或影像，利用檔案共享功能與其他隊員來做即時分享。

圖十七、系統實際使用畫面

圖十七顯示我們所開發之車隊通訊與管理系統的實際使用畫面，圖十七(a)與圖十七(b)分別顯示了自行車上裝備了Android智慧型手機以及車隊成員在騎乘過程中利用車隊通訊功能來與其他成員進行通話，而圖十七(c)與圖十七(d)則是展示了發揮緊急通報功能的受傷情境以及車隊成員間進行車隊競賽的情境。

6. Conclusion

在本篇論文中，我們研究了在上層網路介面為3G/3.5G、下層為IEEE 802.11 Ad-hoc網路、具有共同騎乘路線的自行車車隊網路之資料收集與散佈效率最佳化問題。在此自行車車隊網路架構中，我們設計出自行車車隊成員分群與群組維護的機制，群組成員使用Ad-hoc通訊來交換彼此的資料，並由一個最佳的成員負責回報群組資訊以便Server分享給其他群組，藉由在上下層網路通訊之間的最佳化，可針對3G/3.5G網路在頻寬方面作更有效的利用及減少不必要的花費。此外，我們還實作出一套車隊通訊與管理系統，利用Android智慧型手機作為使用者的手持裝置，可以有效率地達成車隊成員更新位置與狀態資訊的目的。

7. Acknowledgments

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Information Industry which is subsidized by the Ministry of Economy Affairs of the Republic of China.

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GoBike: A Group Communication System for Bikers Based on Smart Phones

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***Abstract*—The GoBike system is a Google Android and Maps-based solution for cycling group communications. On the handset side, an Android program is developed for group member localization, communication, and transmission. On the web side, a biker community site is built for the biker interaction, grouping, and dedicated album. A user who wants to ride a bicycle with other users can first login the community site. Then, he/she can create his/her own cycling group to be joined by others, or just join an existing group. During the cycling activity, all group members can maintain real-time positions and status of other members, notify their emergency events, and share pictures just taken. To provide efficient group communications and reduce the transmission delay, ad-hoc communications are adopted to locally exchange data among bikers. In addition, a grouping mechanism is designed to maintain the stable member connectivity in the ad-hoc environment. On the other hand, the gateway selection in a group takes biker mobility patterns into account for minimizing 3G/3.5G communications. Furthermore, the route throughput estimation is derived to find the fastest path for file transmissions. GoBike thus demonstrates a new group communication system for bikers.**

Keywords: Ad-hoc Communications, Android, Cycling Group, Google Maps, Recreation.

I. Introduction

The bicycling recently has gained a lot of popularity in many applications, such as transportation, recreation, and exercise. People tend to ride bicycles to work instead of driving cars due to the high fuel price. In addition to transportation, on the weekend or vacations, people enjoy riding bicycles in natural environments for both recreation and exercise. Existing works include constructing public bicycle rental system [10], building electric bicycle system [4], and deploying bicycle sensing system [11].

In this work, we are interested in taking advantage of Google Maps APIs [6] and the Android [2] platform to enrich user interaction in a cycling activity. Our goal is to develop a group communication system that individual bikers who do not know each other can be organized and maintained for bicycling together. Traditional cycling services only provide off-line route information, cycling experiences, and sight views of bicycling paths. For the biker grouping, there are two limitations associated with such services. First, bikers must find and contact other group members by themselves. Second, after the cycling activity begins, there is no effective mechanism to maintain the cycling group so that members are easy to lose contacts with each other. Further, communications among members are necessary to keep real-time status of members for cycling safety.

Y.-C. Tseng's research is co-sponsored by MoE ATU Plan, by NSC grants 97-3114-E-009-001, 97-2221-E-009-142-MY3, 98-2219-E-009-019, and 99-2219-E-009-003, by MOEA 98-EC-17-A-02-S2-0048 and 98-EC-17-A-19-S2-0052, Intel Corp., and by ITRI, Taiwan.

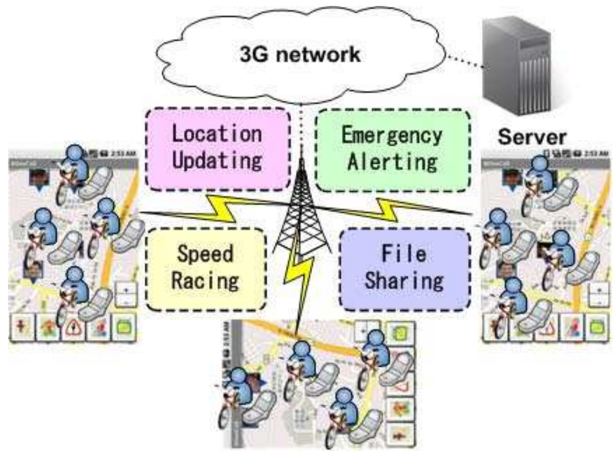

Fig. 1. System architecture of GoBike.

We propose a Google Android and Maps-enhanced group communication system called GoBike. A user just needs to create or join a cycling group before cycling, and only an Android-based smart phone is needed to maintain the cycling group during the cycling activity. On the handset side, an Android program is developed for group member localization, communication, and transmission. On the web side, a biker community site is built for biker interaction, grouping, and dedicated album. A user who wants to ride a bicycle with other users can first login the bike community site. Then, he/she can create his/her own cycling group to be joined by others, or just join an existing group. During the cycling activity, all group members can maintain real-time positions and status of other members, notify their emergency events, and share pictures just taken. GoBike thus demonstrates a new group communication system for bikers.

II. System Design

Fig. 1 shows the GoBike architecture. On the handset side, the developed Android program called BiSeeCall consists of group member localization, communication, racing, emergency notification, and file sharing. In addition, a backend server is installed to handle connections and exchange data

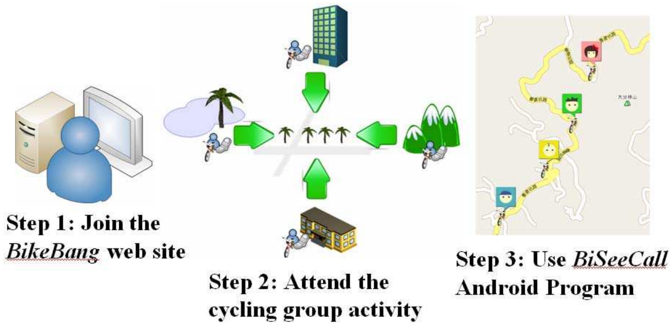

Fig. 2. Cycling group application.

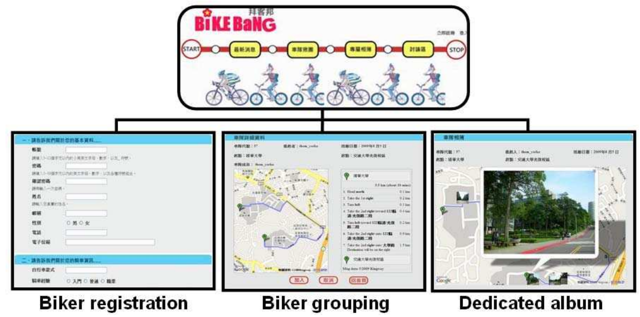

Fig. 4. BikeBang community site.

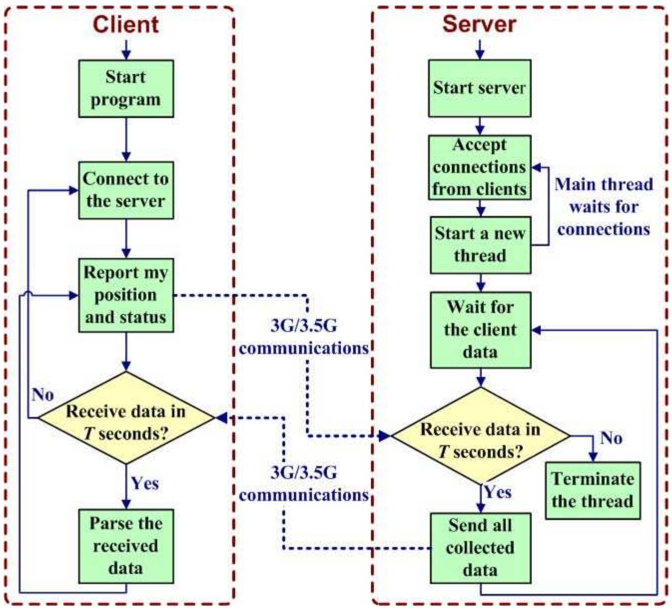

Fig. 3. Flowchart of BiSeeCall.

among group members. On the web side, the biker community site called BikeBang is built for the biker interaction, grouping, and dedicated album. To illustrate how GoBike works, we demonstrate a cycling group application below. As shown in Fig. 2, the user browses the BikeBang site at home and registers a user account for cycling grouping, which he/she can plan a preferred cycling path and then create a new group, or directly join an existing group. On the cycling day, bikers go to the cycling location from different places, and one of them will be the group leader.

During the cycling activity, all positions and status of members can be shown on the BiSeeCall Android program. By simply clicking member icons on the phone screen, users can immediately make phone calls or transmit short messages to other bikers. When users take pictures or record videos along the cycling path, they can immediately share these files with other members through the file sharing function in BiSeeCall. On one hand, the group leader can announce that the group racing will begin after a certain duration. On the other hand, if some user encounters an emergency event (such as bicycle crashing), he/she can send a notification message to other members for help. Furthermore, if the leader can not do his/her duty due to emergency events or other reasons, he/she can pass the leadership to one of other members for keeping the activity goes on. After the cycling activity is finished, this cycling group owns a dedicated album on the BikeBang site to show pictures taken along its cycling path.

Fig. 3 shows the flowchart of BiSeeCall. The time threshold T is used to detect and recover the disconnections between clients and the server caused by the congestion of 3G/3.5G transmissions. To further overcome the uncertain delay problem and provide efficient group communications among bikers, the following issues have been taken into consideration.

1) Since all members must connect to the backend server, transmit individual status to it, and receive the collected group information via 3G/3.5G communications, the transmission delay is high for location updating and data exchanging among them. For reducing the number of 3G/3.5G connections, IEEE 802.11 ad-hoc communications are adopted to exchange information locally, and only the selected gateways need to transmit the aggregated data to the backend server.
2) Bikers properly ride in different speeds due to their body strengthes and bike performance. Thus, group members will form vehicular long-thin networks (VLTNs) along the cycling path. The grouping mechanism is designed to maintain a stable VLTN topology in the ad-hoc environment.
3) During the cycling activity, group members tend to follow the similar mobility pattern that is riding along the predefined cycling path. The gateway selection of VLTNs takes biker mobility patterns into account for minimizing 3G/3.5G communications.
4) Furthermore, in a multi-rate VLTN, the shortest path (with the smallest hop count) may not be the fastest path (with the lowest transmission time) to share files because the links of the shortest path have long distances and thus low bandwidth. The route throughput estimation is derived to find the fastest path for file sharing among bikers.

III. Prototype Implementation

Fig. 4 shows main functions in the BikeBang site, which includes the biker interaction, grouping, and dedicated al-

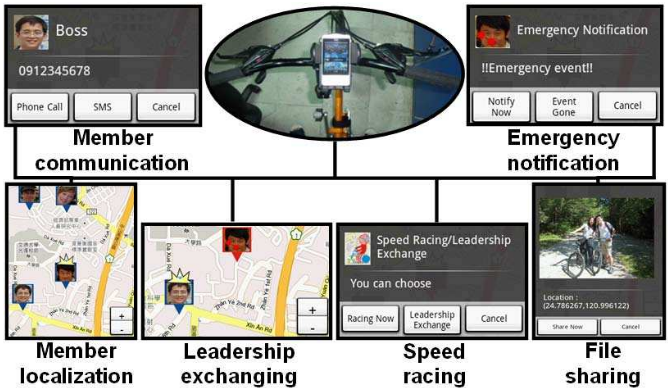

Fig. 5. BiSeeCall Android program.

Fig. 6. Group communication demonstration.

bum. The planning of group cycling paths in BikeBang is implemented by Google Maps APIs [6] with detailed street and landmark information. Google Maps is a well-known application and technology provided by Google, which is free for non-commercial use and powers many map-based services. It offers street maps and a route planner for traveling by foot, car, or public transportation in many countries around the world.

The web server of BikeBang is implemented by Apache version 2.2.11 [3], which is developed and maintained by an open community of developers. Apache is available for a wide variety of operating systems, such as Unix, FreeBSD, Linux, Solaris, Novell NetWare, Mac OS X, and Microsoft Windows. The database system of BikeBang is implemented by PostgreSQL version 8.4 [9], which is an object-relational database management system (ORDBMS). The interface between Apache and PostgreSQL is implemented by PHP version 5.2.1 [8], which is a server-side HTML embedded scripting language. PHP can be embedded into HTML and generally runs on a web server that is configured to process PHP code and create web page content from it.

Fig. 5 shows main functions in the BiSeeCall Android program, which includes group member localization, communication, emergency notification, leadership exchanging, speed racing, and file sharing. A backend server is constructed to handle connections and exchange data among group members. Each member periodically reports his/her position and status to the server, and the server replies the collected information of all members in return. In addition to the periodical updating of position and status, bikers can share files with other members on demand, such as pictures/videos just taken/recorded. So the server is also responsible to receive these shared files and send them to other members.

BiSeeCall is an application program running on the Android-based smart phone. Android is a software stack for mobile devices consisting of an operating system, middleware and user applications. It relies on Linux version 2.6 for core system services including security, memory management, process management, network stack, and driver model. We use the Java Development Kit (JDK) [7] and the Eclipse integrated development environment (IDE) [5] in Android programming and its IDE, respectively. The Eclipse IDE is a multi-language software development environment comprising an IDE and a plug-in system to extend it. It is primarily written in Java and can be used to develop applications in many languages, such as C, C++, COBOL, Java, Python, Perl, PHP, and etc.

To develop BiSeeCall more efficiently, Android Development Tools (ADT) Plugin [1] is installed to add useful extensions to the Eclipse IDE, which makes creating and debugging Android applications easier and faster. The software development kit (SDK) of BiSeeCall uses the Android SDK [2], which provides the essential tools and APIs to begin developing applications on the Android platform using the Java programming language. It includes a debugger, libraries, a handset emulator, documentation, sample code, and tutorials.

For cycling group communications, Fig. 6(a) and Fig. 6(b) show Android-based smart phones set up on bicycles and a biker use BiSeeCall to communicate with other members as riding, respectively. We demonstrate a emergency notification scenario as shown in Fig. 6(c) and a speed racing scenario as shown in Fig. 6(d).

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An Augmented Reality Based Group Communication System for Bikers Using Smart Phones

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***Abstract*—The bicycling recently has gained a lot of popularity in many applications, such as transportation, recreation, and exercise. Bikers may ride in different speeds due to their body strengthes and bike performance such that group members using smart phones form two-tier vehicular long-thin networks along the common cycling path, which consist of a 3G/3.5G high-tier interface and an IEEE 802.11-based low-tier interface. In this paper, we design a Google Android and Maps-based solution for cycling group communications. On the handset side, an Android program is developed for group member localization, communication, and transmission. In addition, the augmented reality interface is integrated to show the biker information on real-time camera views of smart phones. On the web side, a biker community site is built for the biker interaction, grouping, and dedicated album. To provide efficient group communications and reduce the transmission delay, ad-hoc communications are adopted to locally exchange data among bikers. Also, a dynamic grouping mechanism has been designed to maintain the stable member connectivity in ad-hoc environments. Furthermore, the gateway selection in a group has taken the similar mobility pattern of members into account for minimizing 3G/3.5G communications.**

Keywords: Ad-hoc Communications, Android, Augmented Reality, Cycling Group, Google Maps.

I. Introduction

The bicycling recently has gained a lot of popularity in many applications, such as transportation, recreation, and exercise. People tend to ride bicycles to work instead of driving cars due to the high fuel price. In addition to transportation, on the weekend or vacations, people enjoy riding bicycles in natural environments for both recreation and exercise. Existing works include constructing public bicycle rental system [10], building electric bicycle system [4], and deploying bicycle sensing system [11].

In this work, we are interested in taking advantage of Google Maps APIs [6] and the Android [2] platform to enrich user interaction in a cycling activity. In addition, the augmented reality interface is integrated to show the biker information on real-time camera views of smart phones. Our goal is to develop an group communication system that individual bikers who do not know each other can be organized and maintained for bicycling together. Traditional cycling services only provide off-line route information, cycling experiences, and sight views of bicycling paths. For the biker grouping,

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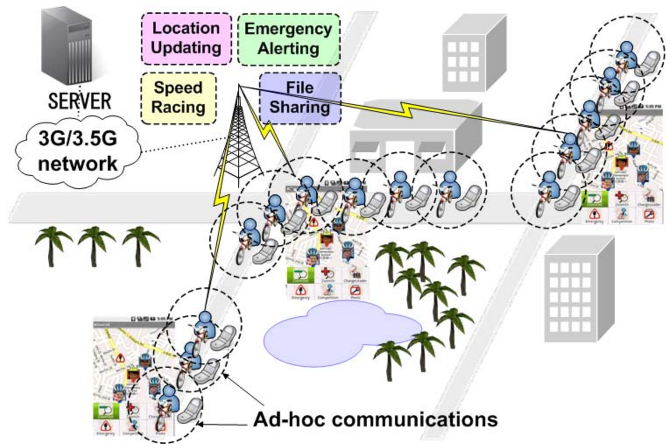

Fig. 1. System architecture of cycling group communications.

there are two limitations associated with such services. First, bikers must find and contact other group members by themselves. Second, after the cycling activity begins, there is no effective mechanism to maintain the cycling group so that members are easy to lose contacts with each other. Further, communications among members are necessary to keep real-time status of members for cycling safety.

For cycling group communications, a backend server is installed to handle connections and exchange data among group members. Bikers periodically upload their location data to the server and download the collected information from the server. Since all members must connect to the backend server, transmit individual status to it, and receive the collected information via 3G/3.5G communications, the bandwidth usage and transmission delay are high for location updating and data exchanging among them.

To solve this problem, IEEE 802.11 ad-hoc communications are adopted to exchange information locally, and only the selected gateways need to transmit the aggregated data to the backend server. On the other hand, bikers properly ride in different speeds due to their body strengthes and bike performance. Thus, group members will form two-tier vehicular long-thin networks (VLTNs) along the common cycling path. The dynamic grouping mechanism has been designed to maintain a stable VLTN topology in ad-hoc environments. During the cycling activity, group members tend to follow the similar mobility pattern that is riding along the predefined cycling path. The gateway selection of VLTNs has taken

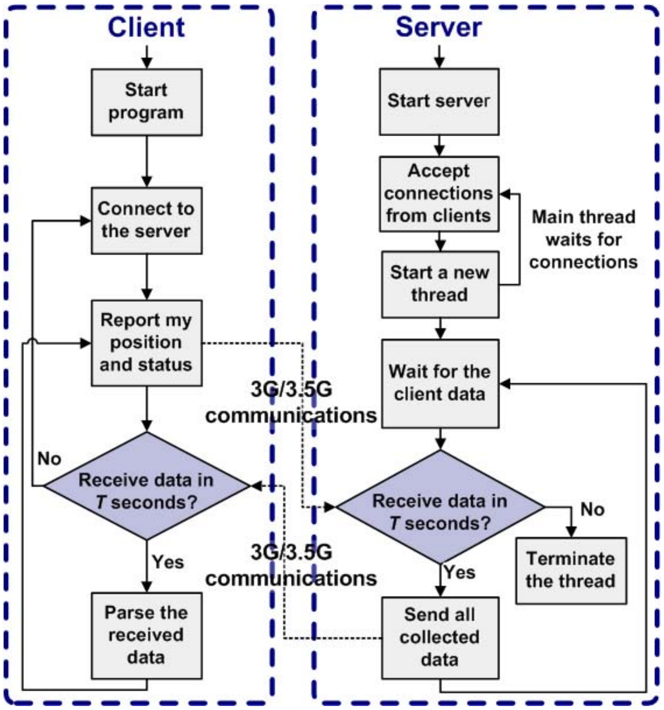

Fig. 2. Flowchart of BiSeeCall-AR.

biker mobility patterns into account for minimizing 3G/3.5G communications.

II. System Design

Fig. 1 shows the architecture of cycling group communications, which consists of three ad-hoc communication groups. On the handset side, the developed augmented reality based Android program called BiSeeCall-AR consists of group member localization, communication, racing, emergency notification, and file sharing, which a backend server is installed to handle connections and exchange data among group members. On the web side, the biker community site called BikeBang is built for the biker interaction, grouping, and dedicated album.

To illustrate how the group communication system works, we demonstrate a cycling group application below. The user browses the BikeBang site at home and registers a user account for cycling grouping, which he/she can plan a preferred cycling path and then create a new group, or directly join an existing group. On the cycling day, bikers go to the cycling location from different places, and one of them will be the group leader. During the cycling activity, all positions and status of members can be shown on BiSeeCall-AR. By simply clicking member icons on the phone screen, users can immediately make phone calls or transmit short messages to other bikers. When users take pictures or record videos along the cycling path, they can immediately share these files with other members through the file sharing function in BiSeeCall-AR.

On one hand, the group leader can announce that the group racing will begin after a certain duration. On the other hand, if some user encounters an emergency event (such as bicycle crashing), he/she can send a notification message to other

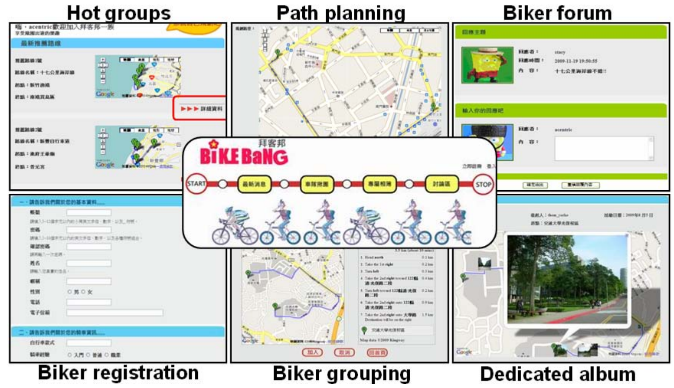

Fig. 3. BikeBang community site.

members for help. Furthermore, if the leader can not do his/her duty due to emergency events or other reasons, he/she can pass the leadership to one of other members for keeping the activity goes on. After the cycling activity is finished, this cycling group owns a dedicated album on the BikeBang site to show pictures taken along its cycling path.

Fig. 2 shows the communication flowchart of BiSeeCall-AR. The time threshold T is used to detect and recover the disconnections between clients and the server caused by the congestion of 3G/3.5G transmissions. To further overcome the uncertain delay problem and provide efficient group communications among bikers, the data collection and distribution problem in two-tier VLTNs is defined as follow.

Denote a cycling fleet network by an undirected graph $G(V, E)$, where V is the set of fleet members v and E is the set of low-tier communication links e. If any two v are within low-tier communication ranges of each other, there exists a e between them. Let $C \subseteq G$ be a connected graph that there is a sequence of e for any two v in C. Define that a long-thin group $L \subseteq C$ consists of a gateway g and a number of v. During the data collecting process, each $v \in L$ transmits its location data d_L to g via a sequence of e and g collects all d_L of $v \in L$. Then, g reports all d_L to the server S and obtains the fleet information d_F of all $L \subseteq G$ from S via high-tier communications. During the data distributing process, g broadcasts d_F to all $v \in L$ via a sequence of e. To provide efficient fleet communications and reduce the transmission delay, we consider the following four issues in our dynamic grouping mechanism and group maintenance scheme.

1) Biker Grouping: How do we group a $L \subseteq C$ so that the delay bound of the data collection and distribution can be satisfied?
2) High-tier Efficiency: How do we select a g in L so that high-tier communications can be minimized?
3) Routing and Scheduling: How do we decide the routing path and transmission order of each $v \in L$ so that the packet collision rate can be minimized?
4) Data Aggregation: How do we aggregate each d_L of $v \in L$ so that the amount of data transmitted can be minimized?

Fig. 4. BiSeeCall-AR Android program.

Fig. 5. Group communication demonstration.

III. Prototype Implementation

A. BikeBang Community Site

Fig. 3 shows main functions in the BikeBang site, which includes the biker registration, grouping, forum, dedicated album, path planning, and hot groups. The planning of group cycling paths in BikeBang is implemented by Google Maps APIs [6] with detailed street and landmark information. The web server of BikeBang is implemented by Apache version 2.2.11 [3], which is developed and maintained by an open community of developers. Apache is available for a wide variety of operating systems, such as Unix, FreeBSD, Linux, Solaris, Novell NetWare, Mac OS X, and Microsoft Windows. The database system of BikeBang is implemented by PostgreSQL version 8.4 [9], which is an object-relational database management system (ORDBMS). The interface between Apache and PostgreSQL is implemented by PHP version 5.2.1 [8], which is a server-side HTML embedded scripting language. PHP can be embedded into HTML and generally runs on a web server that is configured to process PHP code and create web page content from it.

B. BiSeeCall-AR Android Program

Fig. 4 shows main functions in the BiSeeCall-AR Android program, which includes group member localization, communication, emergency notification, leadership exchanging, speed racing, and file sharing. The GPS and m-sensor are used to obtain member locations and angle directions to show biker information tags on related positions of the camera view. A backend server is constructed to handle connections and exchange data among group members. Each member periodically reports his/her position and status to the server, and the server replies the collected information of all members in return. In addition to the periodical updating of position and status, bikers can share files with other members on demand, such as pictures/videos just taken/recorded. So the server is also responsible to receive these shared files and send them to other members.

BiSeeCall-AR is an application program running on Android-based smart phones. Android is a software stack for mobile devices consisting of an operating system, middleware and user applications. It relies on Linux version 2.6 for core system services including security, memory management, process management, network stack, and driver model. We use the Java development kit (JDK) [7] and the Eclipse integrated development environment (IDE) [5] in Android programming and its IDE, respectively. To develop BiSeeCall-AR more efficiently, Android Development Tools (ADT) Plugin [1] is installed to add useful extensions to the Eclipse IDE, which makes creating and debugging Android applications easier and faster. The software development kit (SDK) of BiSeeCall-AR uses the Android SDK [2], which provides the essential tools and APIs.

C. Demonstration

For cycling group communications, Fig. 5(a) and Fig. 5(b) show Android-based smart phones set up on bicycles and a biker use BiSeeCall-AR to communicate with other members as riding, respectively. We demonstrate an emergency notification scenario as shown in Fig. 5(c) and the speed racing for group members as shown in Fig. 5(d).

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An Infrastructure-less Framework for Preventing Rear-End Collisions by Vehicular Sensor Networks

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***Abstract*—We consider *vehicular sensor networks (VSNs)* consisting of a large number of sensor nodes deployed on vehicles to facilitate vehicular applications. We try to apply such VSNs to preventing rear-end collisions that are common accidents due to sharp stops. An infrastructure-less framework is proposed, which only relies on vehicles' onboard sensors to prevent such accidents. The proposed framework consists of a distributed warning protocol and a location-based backoff scheme. Vehicle-to-vehicle communications is used to form *warning groups*, where a warning group is a set of vehicles that drive along the same lane and every pair of adjacent cars is within a certain distance. Only single-hop transmissions are needed to join and leave a group, thus keeping the group maintenance overhead low. When a sudden brake event is detected in a warning group, the location-based backoff scheme can quickly propagate warning messages among its group members. Simulation results show that the proposed approach outperforms existing schemes.**

Keywords: Collision Prevention, IEEE 802.11p, Traffic Safety, Vehicular Sensor Network.

I. Introduction

Recent advances in vehicular communication technologies and embedding sensing MEMS make *vehicular sensor networks (VSNs)* possible. Such systems have the advantages of both *vehicular ad hoc networks (VANETs)* and *wireless sensor networks (WSNs)*. This leads to many applications, such as traffic safety [1] and vehicle security [5]. VSNs consist of many sensor nodes deployed on roads or vehicles, which co-operate through *vehicle-to-vehicle (V2V)*, *vehicle-to-roadside (V2R)*, and *vehicle-to-infrastructure (V2I)* communications.

This work focuses on preventing rear-end collisions among vehicles by V2V communications. References [4], [7] rely on roadside infrastructures to achieve this goal, but this is sometimes not feasible in suburban and rural areas. Brake-warning based on vehicular networks has been studied in [1], [2], [11]. Reference [1] deals with frontal collisions due to improper overtaking. Reference [11] presents an intelligent V2V broadcast with implicit acknowledgment for highway safety. In comparison, our design consists of a distributed warning protocol and a location-based backoff scheme to further reduce the number of warning messages. Reference [2] also uses V2V communications to avoid rear-end collisions on highways. However, the scheme relies on obtaining lane IDs through infrastructure roadside units. In addition, too many vehicles may be warned unnecessarily, causing high message overheads. Contrarily, our infrastructure-less framework avoids chained vehicle collision due to emergency brake with efficient and quick message exchange.

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II. Problem Definition

We consider vehicles on the roads that form VSNs via V2V communications. Each vehicle is equipped with a GPS receiver and a distance sensor (such as a magnetic sensor [1] or a laser range finder [9]) in its front end. GPS can provide a vehicle's absolute position and velocity. The distance sensor is directional and can detect the distance of a vehicle to the one in its front. This also implies the possibility of estimating the velocity of the vehicle in its front. We assume that IEEE 802.11p [3] is used with the WAVE (Wireless Access in Vehicular Environments) mode to support V2V communications. Periodical beacons containing vehicles' IDs and positions are transmitted by each vehicle to their neighbors. Note that although the distance between two vehicles can be estimated by GPS outputs, message exchange between these two vehicles is needed. In our model, employing distance sensors can obtain the same result and is communication-free.

The *rear-end collision avoidance problem* is defined as follow. Each radio interface has a fixed transmission range R. Each vehicle i has to keep a safety distance of d_i^s from the vehicle in front of it. According to the "two-second" rule [6], we set $d_i^s = s_i \times \delta$, where s_i is the current speed of i and $\delta = 0.55$. We will form dynamic *warning groups* for vehicles on the road, where a warning group is a sequence of vehicles in the same lane such that each vehicle does not keep a safety distance from the vehicle in its front except the first one.

Our goal is to design an efficient protocol for vehicles to join/leave their warning groups. In addition, when any vehicle i of a group takes an emergency brake, a warning message should be sent immediately to those vehicles behind i in the same group. Such warning messages have the highest priority and may be delivered through multi-hop forwarding. Therefore, drivers can become aware of such events even before they actually see the braking signals.

III. The Proposed Framework

We propose an infrastructure-less framework. A distributed warning protocol is proposed in Section III-A. To quickly propagate emergent braking events, a location-based backoff scheme is presented in Section III-B.

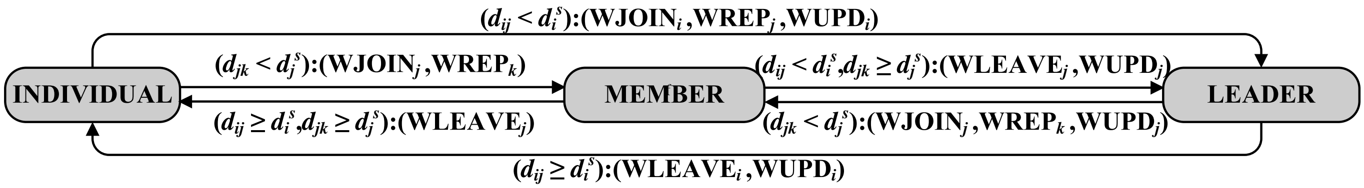


Fig. 1: State transition diagram of vehicle j, where j is immediately in front of vehicle i and behind vehicle k.

A. Distributed Warning Protocol

Our scheme consists of a mutual-warning mechanism and a self-warning mechanism. We first discuss the mutual-warning part. Assume that vehicle i is immediately behind vehicle j in the same lane. Let d_{ij} be the distance between i and j. Recall the safety distance d_i^s. If $d_{ij} \geq d_i^s$, no action is needed; otherwise, we will put i and j into one warning group. When i detects this situation, it will broadcast a WJOIN message with its current location and ID. Based on i's position, j can determine that it is immediately in front of i. Then j will reply a WREP message with the ID of its group leader and add i into its 1-hop warning list. If there is no vehicle in front of j or j has kept in safety distance from the vehicle in front of it, j will form a new group and serve as the group leader; otherwise, the group leader is the first vehicle in the chain of vehicles not keeping in safety distances with each other. On the other hand, if later on the safety condition $d_{ij} \geq d_i^s$ holds, i will send a WLEAVE message to j to leave j's group. In response, j will remove i from its 1-hop warning list. Note that WJOIN, WREP, and WLEAVE are local (1-hop) broadcasts, so the control overhead should be quite low.

Let i immediately follow j and j immediately follow k in the same lane. We summarize the states of j as follows:

- $INDIVIDUAL$: i keeps in safety distance from j and so does j from k.
- $LEADER$: j keeps in safety distance from k, but i does not keep in safety distance from j.
- $MEMBER$: j does not keep in safety distance from k.

Whenever j transits to the LEADER state, it broadcasts a WUPD message to its group members. Whenever j is in the LEADER/MEMBER state and performs an emergency brake, it immediately broadcasts a WARN message to the group members behind it. A vehicle only accepts a WUPD/WARN message from a vehicle in front of it in the same warning group. Both WUPD and WARN need to be rebroadcast (see Section III-B). Fig. 1 shows the state transition diagram of j, where the label on each transition edge is formatted as (event):(action). For instance, $(d_{jk} < d_j^s)$:(WJOIN$_j$, WREP$_k$) represents that as $d_{jk} < d_j^s$ is detected, j broadcasts a WJOIN message and then k replies a WREP message. Note that due to GPS errors, some neighboring vehicles in different lanes may incorrectly reply WREP messages to a WJOIN message. A vehicle may thus belong to multiple warning groups at the same time, and a warning group may include vehicles in neighboring lanes. However, this only causes our system to warn extra vehicles, but would not cause problems.

Next, we discuss the self-warning mechanism when i is too close to j, which is in front of i. We define a driver's *Needed Maneuvering Time (NMT)* to be the sum of needed reaction time η (from seeing a braking signal to taking an emergency brake) and emergency braking time. This value must be less than the *Available Maneuvering Time (AMT)*. Suppose that j takes an emergency brake at the maximum braking acceleration a_j. Then, after time interval Δt, j will move a distance of $B_j(\Delta t) = s_j \times \Delta t + \frac{1}{2} \times a_j \times \Delta t^2$, where s_j is the current speed of j. Also, $B_j(\frac{s_j}{a_j})$ is the total moving distance before j fully stops. To ensure a sufficient AMT when j takes an emergency brake, d_{ij} must satisfy the following condition for any time interval Δt before i fully stops:

$$B_j(\Delta t) + d_{ij} > \begin{cases} s_i \times \Delta t & , \ 0 < \Delta t \leq \eta \\ s_i \times \eta + B_i(\Delta t - \eta) & , \ \eta < \Delta t \leq \eta + \frac{s_i}{a_i} \end{cases} .$$

According to [8], η is about 1.5 second in average, which is a major part of NMT. The upper part in the above inequality is the distance before i starts to brake, while the lower is that after i starts to brake. If the condition is violated for any Δt, the onboard unit of i will warn its driver to keep a longer distance from j.

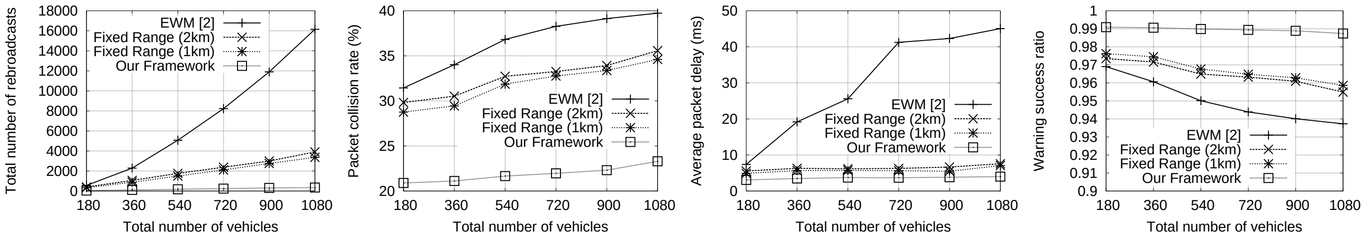
B. Location-based Backoff Scheme

To reduce the number of WUPD and WARN messages, we design a location-based backoff scheme. It facilitates farther receivers from the sender to rebroadcast at earlier time. Each WARN message contains the sender's position, group leader ID, and a sequence number. When vehicle j receives a WARN message, j first checks whether the message is sent from j's warning group (according to the group leader ID) and the sender is in front of j. If so, j will calculate the distance d_j^w between itself and the sender. A larger value of d_j^w will give a smaller backoff timer BT_j, as defined below:

$$BT_j = \begin{cases} [0, 2^{\tau+1} - 1] & \frac{\rho-1}{\rho} R < d_j^w \leq R \\ [2^{\tau+1}, 2^{\tau+2} - 1] & \frac{\rho-2}{\rho} R < d_j^w \leq \frac{\rho-1}{\rho} R \\ \vdots & \\ [2^{\tau+\rho-1}, 2^{\tau+\rho} - 1] & 0 < d_j^w \leq \frac{1}{\rho} R \end{cases} ,$$

where $\rho = \lceil \frac{R}{d_j^s} \rceil$, R is the transmission range, and τ is a small integer. Thus, this gives farther receivers higher priorities to rebroadcast.

On the other hand, an implicit inhibition strategy is adopted to eliminate redundant WARNs. Specifically, the reception of a WARN from a vehicle in the back of j in the same group serves as an implicit message to prevent j from competing again. On receiving such a rebroadcast, j will remove the message in its waiting queue. Furthermore, to improve reliability,



(a) (b) (c) (d)

Fig. 2: Comparisons of (a) total number of rebroadcasts, (b) packet collision rate, (c) average packet delay, and (d) warning success ratio.

a vehicle which already sent the WARN message will try to overhear any rebroadcasting from any vehicle behind it. If it can not overhear any such rebroadcasting, it will rebroadcast again with a new sequence number. We recommend that such rebroadcasting be executed at most once. Note that WUPD messages are rebroadcast similarly.

IV. Performance Evaluation

We simulate the proposed framework by QualNet 4.5 [10] with some modifications. The two-ray ground radio model and IEEE 802.11p MAC protocol are adopted. A 10-km six-lane highway (three lanes per direction) with 180, 360, 540, 720, 900, and 1080 vehicles is simulated. 20% of vehicles are randomly chosen to take emergency brakes. The broadcast power is set to 32 mW. The normal speed and emergency deceleration speed are set to 25 m/s and 8 m/s^2, respectively. We set $R = 300$ m, $\eta = 1.5$ s, and $\tau = 1$. We compare our scheme against a simple Fixed Warning Range (FWR) method that warns vehicles in 1 km or 2 km behind the vehicle taking an emergency brake and the Emergency Warning Message (EWM) method [2] that warns vehicles in the same lane behind the vehicle taking an emergency brake. The main performance indices are the total number of rebroadcasts, packet collision rate, average packet delay, and warning success ratio. Each simulation is repeated 100 times and then we take the average value.

Fig. 2(a) illustrates the total numbers of rebroadcasts under different numbers of vehicles. We can observe that our scheme has the lowest number of rebroadcasts. More importantly, while the number of rebroadcasts of EWM increases exponentially as the number of vehicles increases, that of ours only increases linearly. This is because our scheme only warns the vehicles without following safety distances so that its total number of rebroadcasts is proportional to the warning group size instead of the total number of vehicles. On the contrary, EWM will warn too many unnecessary vehicles in the same lane about emergency brake so that its total number of rebroadcasts dramatically increases with the total number of vehicles. Note that with less than 180 vehicles, the network connectivity becomes very low and all schemes perform about the same.

Fig. 2(b) and Fig. 2(c) show the packet collision rates and average packet delays under different numbers of vehicles, respectively. It can be observed that our scheme still outperforms FWR and EWM. The reason is similar to what is discussed earlier. In addition, our location-based backoff scheme can further reduce these indices because we prioritize WARN messages.

Fig. 2(d) shows that the above advantages will lead to the highest warning success ratio for our scheme. In particular, our location-based backoff scheme significantly improves the warning success ratio because re-broadcasters are assigned with different contention windows based on their locations and our overhearing mechanism does help increase the reliability of warning messages.

From these results, we conclude that the proposed approach can achieve the best performance, leading to more efficient use of wireless bandwidth. In other words, adopting our scheme in vehicular networks can both avoid transmissions of emergency messages wasting bandwidth due to unnecessary rebroadcasts and prevent emergency messages from transmission collisions caused by serious packet contention.

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Design and Implementation of a Bicycle Tour Logging System Based on Smart Phones

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摘要

自行車使用者出遊時常會面臨一些狀況，例如臨時想要查詢與分享旅遊記錄，或在旅程中使用手機時發現電量不足等。在資訊科技的蓬勃發展下，行動計算可以大幅增進騎乘自行車的便利性，而我們所設計的樂活單車通(LOHAS BikeTel)結合了智慧型手機、感測器、GPS 定位系統、Google Map 與充電裝置，使得路徑資訊與遊記收集分享等功能可以更方便地應用在單車旅行中。在 LOHAS BikeTel 中，自行車使用者能夠：(1)利用語音辨識，將口述心得轉成文字上傳至所建構的 LOHAS BikeLog 部落格或 Facebook 社群網站；(2)記錄上傳旅行照片、GPS 路徑資訊，或搜尋他人的旅遊記錄；(3)利用 GPS 省電演算法節省使用 GPS 的電力消耗，並搭配坡度資訊與充電模組來進行充電以延長手機使用時間，LOHAS BikeTel 提供了騎士間新型的社群資訊交流平台。

關鍵字：Android、GPS 省電演算法、資通訊技術、位置感知服務、智慧型手機

ABSTRACT

Cyclists frequently encounter some troubles during their bicycle tours, such as that cyclists cannot search, log or share the travel record to their friends, and the mobile phone sometimes is out of battery in the cycling. This paper proposes a bicycle tour logging system, called LOHAS BikeTel, that combines smart phones, sensors, GPS, and Google Map to provide the following features: (1) cyclists can upload and share their text messages by speech recognition to LOHAS BikeLog or Facebook by smart phones, (2) users can track their cycling path and show the pictures just taken during their bicycle travel tours, (3) it adopts GPS power-saving algorithm to prolong the battery lifetime and helps cyclists recharge their batteries by charging devices based on slope information. LOHAS BikeTel provides a new social platform for cyclists.

Key Words: Android, GPS Power-saving Algorithm, Information and Communication Technology, Location-based Service, Smart Phone

1 前言

1.1 背景與動機

由於無線網路的使用日漸普及，目前各大相關產業亦致力於開發及支援各種無線上網的新產品，有鑑於此，若可善加利用無線網路系統，將可開發出有別於以往的應用，以達到良好的管理及更為便利的使用者環境。另一方面，近年來由於高油價與綠能環保意識的興起，各種不同的交通替代方法紛紛出現。以自行車為交通工具是既省錢又環保的代步方式[1]，所以騎乘自行車成為一個政府大力推廣的活動。然而自行車騎士經常會面臨要如何找到一條具備安全、長度適中、景觀優美的騎乘路線這一類的問題[2, 3, 4, 5]。較有經驗的騎士通常會在反覆試驗、不斷摸索的過程中或是與其他騎士的經驗交流中建立起自己的一套旅遊路線。在現今資訊科技的蓬勃發展下，智慧手機軟硬體技術的進步使得現今的手機已具備行動上網、多媒體處理、GPS 訊號接收、三軸重力感測等功能[6, 7]。因此本論文嘗試結合手機科技與自行車騎乘潮流，以 Android 智慧型手機為平台，實作一個自動化的服務系統—樂活單車通。

1.2 相關文獻探討

就發展現況而言，室外定位主要利用基礎通訊系統(Infrastructure)所提供相關的位置資訊或是利用全球化定位系統（Global Positioning System, GPS）來達成，GPS 已是一套普遍應用的成熟技術，其定位原理是先接收多個衛星的定位訊號再利用三角定位法來計算位置。一般智慧型手機所採用的 GPS 接收器為美國國家海洋電子協會(National Marine Electronics Association, NMEA)[8]所制定的格式標準，其資料格式有 0180、0182 和 0183 三種格式。本論文所採用的 Android 智慧型手機使用 NMEA 0183 格式。

文獻[9, 10, 11]分別說明利用搭載在自行車的感測器收集環境資訊、GPS 座標定位地圖服務網站的概念與利用 GPS 進行自行車的追蹤與定位。而目前現有的實作系統[12, 13, 14]利用自製地圖，也可以進行路徑追蹤。但在這些研究中只是建置單純的追蹤系統並且記錄一些環境資訊，並無法提供旅遊心得資料整合與即時地上傳騎乘者相關的騎乘資訊至社群網站與其他好友分享。文獻[15]提出了一個創新的移動代理人感測網路路徑定位的概念。文獻[16]提出了一個簡單以三軸加速度計感測行人移動狀態進行 GPS 定位頻率的調整的方法，這個方法雖然可以調整開啟 GPS 的時間，但是仍然是以 GPS 為定位的基礎，當 GPS 由關閉狀態打開時，會需要一段時間來重新完成定位，此時若有較大的位置變化，不易被記錄下來。文獻[17]除了使用三軸加速度計，還加入了使用者行走的歷史軌跡當作判斷的依據，但是系統需要事先完成行人移動資料的收集與分析。

在第二節中，我們介紹 LOHAS BikeTel 系統的架構與設計模式。第三節進一步研設計 GPS 省電演算法，第四節利用 LOHAS BikeTel 系統畫面說明實作成果，第五節則是結論。

2 系統設計

如圖 1 所示，為了結合現有網路社群服務，LOHAS BikeTel 系統設計分為兩個部分，第一部分網站服務端(Web Server)有 LOHAS BikeLog 和 Facebook Web Service。第二部分訪客端(Mobile Device)裝在於自行車上應用程式為 LOHAS BikeLog Client，其主要功能分述如下：

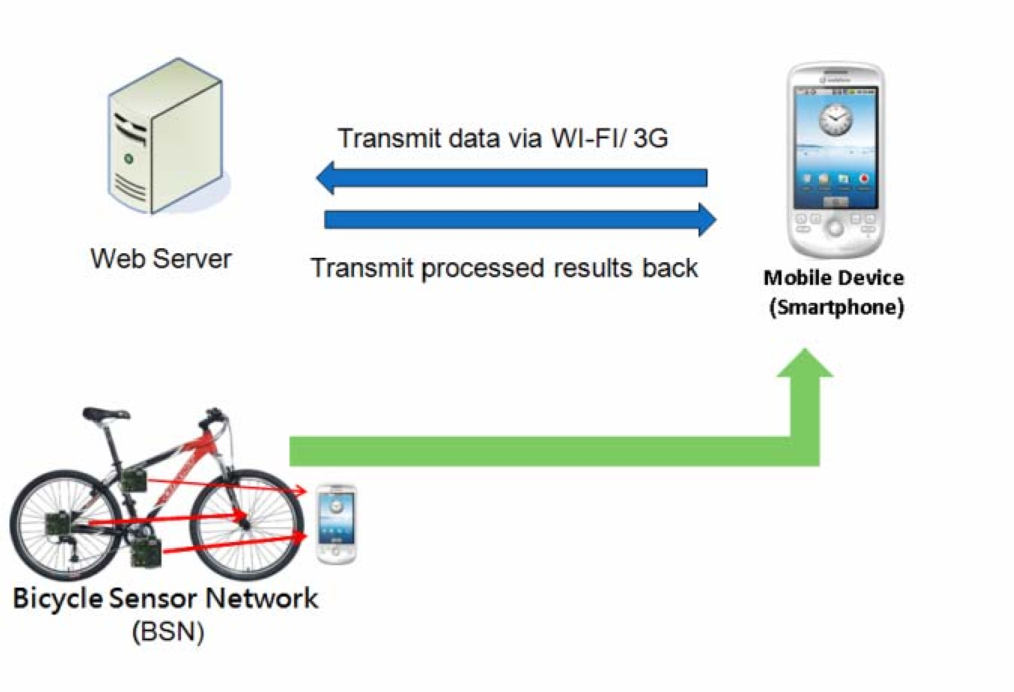


圖 **1**：**LOHAS BikeTel** 系統元件關係圖

a. 網站服務端：

1. 使用者可以看到自己的所有旅遊紀錄與好友公開分享的旅遊紀錄。
2. 使用者可以針對好友傳送文字訊息，如讚美訊息。
3. 尋找路徑服務：這項服務是針對使用個人電腦瀏覽網頁時，可以根據資料庫有哪些路徑資料，提供訪客查詢，並配合訪客端出發時的所在位置，找出到達目的地的路徑。

b. 訪客端：

1. 使用者可以看到目前自己所在位置與經過旅遊的路徑。
2. 使用者可以和網站服務端溝通，並上傳文字訊息發布到網站上。
3. 假如系統使用於某一景點附近，則可以輸入景點的名稱，便可以立即知道使用者位置與該景點附近的相關資訊。
4. 可以觀看系統所傳來的導覽資訊例如圖片，網頁，影音資訊等，還可以回顧之前所傳來的資料。

本論文提出的系統架構如圖2 所示，騎乘者將攜帶具3G 或是Wi-Fi 功能並具有GPS收發器之行動裝置(Mobile Devices)。騎乘途中行動載具將不間斷地接收來自GPS 系統之標準資料，並進行經緯度定位。定位資訊將會透過3G或者是Wi-Fi網路將騎乘者目前相關資料回傳至網路伺服器(Web Server)。系統會員(Members)可經由登入認證來連入網路伺服器。登入系統後可以利用景觀建築、休息站與某些地標來尋找路徑。

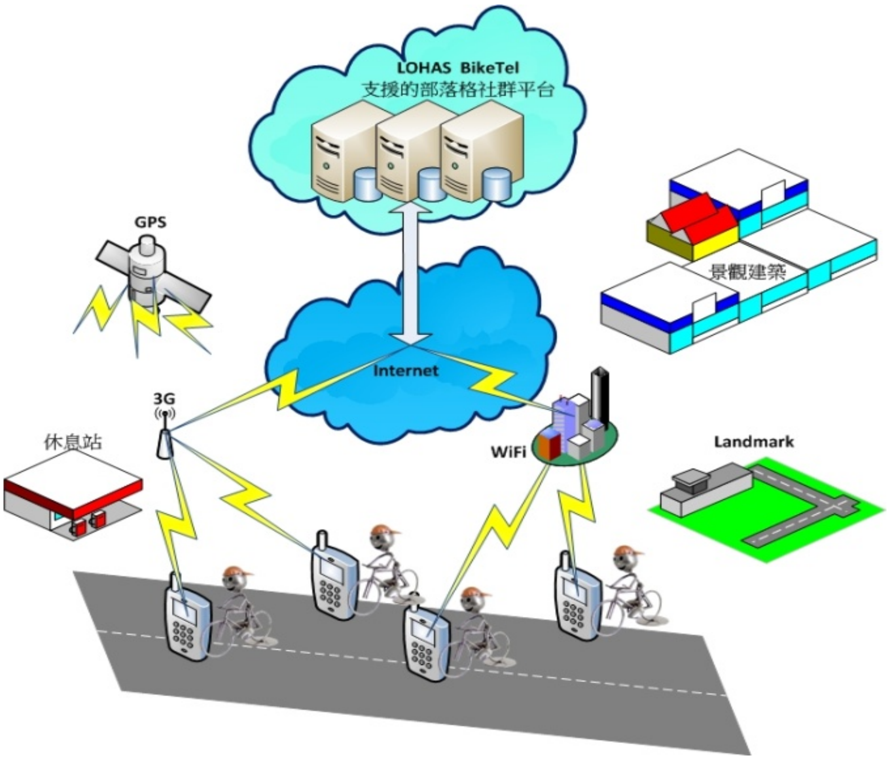


圖2：**LOHAS BikeTel系統架構圖**

2.1 無線基礎架構（Wireless Infrastructure）

因為系統是架設於無線網路基礎建設與 GPS 的接收器上，所以本系統可以利用網路將接收到的 GPS 訊號轉換成位置資訊儲存至網站服務端資料庫。

2.2 行動裝置（Mobile Device）

行動裝置在 LOHAS BikeTel 系統中是以智慧型手機為實作對象，這些行動裝置上在進入網路時會幫使用者的無線上網行動裝置搜尋目前所在位置，搭配手機應用程式提供具有行動特色的旅遊紀錄服務。

2.3 網站伺服器（Web Server）

伺服器主要用來接收行動裝置端所傳送的資料，例如圖片，聲音檔，文字(旅遊紀錄)等，並且為行動裝置使用者建立會員功能，以方便使用者們在此伺服器端上成立社群。

a.會員系統：主要是要透過會員之間的互動來達成分享彼此旅遊記錄的目的，會員註冊成功就可以分享與搜尋公開或者是好友的資料。

b.旅遊紀錄(照片，路徑)查詢：可查閱之前行動裝置所傳過來的照片以及路徑，並可以以折線來表現出會員的路徑。

c.旅遊紀錄(照片，路徑)上傳：可以透過瀏覽器直接上傳照片、路徑。

2.4 應用程式介面

所有的手機應用程式都會透過應用程式介面跟 Web Server 做溝通，如圖 3 應用程式元件架構如下：

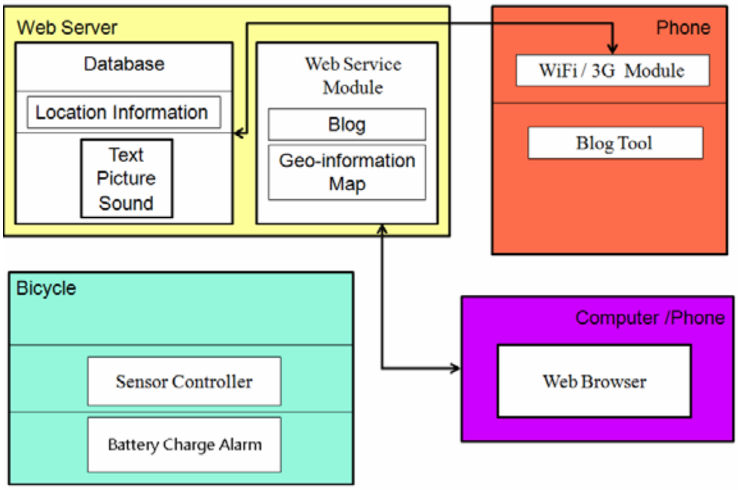


圖 3：**LOHAS BikeTel 軟體元件關係圖**

在 Web Server 中提供 Blog、Geo-information Map 網頁與資料庫服務，其中 Blog 網頁服務稱為 LOHAS BikeLog，LOHAS BikeLog 提供介面讓自行車騎士將旅行過程中所拍下的照片、聲音或者是文字訊息與好友分享。另外，Geo-information Map 網頁服務可以讓使用者查詢自己與好友過去的旅遊路線。而上述的照片、聲音、文字訊息與路徑資料皆存放於 Web Server 資料庫中。手機(Phone)裝載於自行車上，提供自行車騎士路徑與遊記紀錄的工具。

3　GPS 省電演算法

根據 1.2 節相關文獻探討結果可知，持續長時間地開啟 GPS 定位，會消耗大量電能使得手機的電池快速耗盡，因此有必要動態調整 GPS 接收器開啟的時間以延長整體手機的使用時間。在本節中，我們將設計一個 GPS 省電演算法動態地調整 GPS 接收器開啟與定位記錄的頻率，以達到省電的效果。為了避免關閉 GPS 的時間太長影響到定位的精度或者是漏失某些關鍵的旅程記錄，所以我們的演算法結合自行車旅行的路徑特徵與手機內嵌式感測器的移動偵測，來做回饋調整，以期在省電模式下 LOHAS BikeTel 系統仍可以維持定位精度與旅遊紀錄功能，圖 4 顯示省電演算法元件方塊圖。

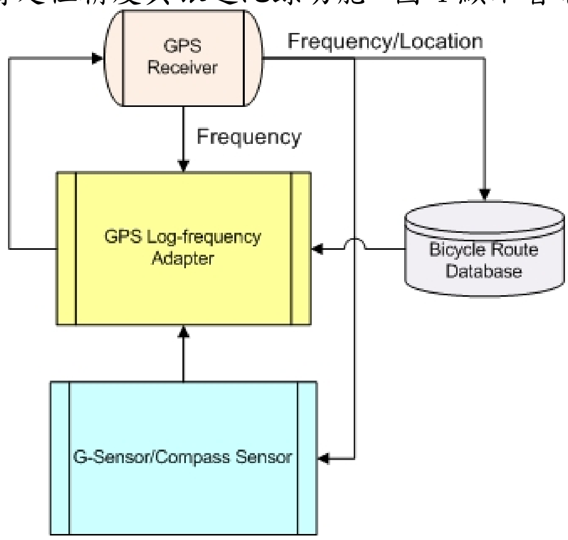


圖**4**：**省電演算法元件方塊圖**

一開始當 GPS Receiver 開啟後會以系統預設記錄頻率 1 Hz 去接收 GPS 定位訊號，接著將其接收到的訊號與目前的記錄頻率傳送到以下三個模組：GPS Log-frequency Adapter、Bicycle Route Database 與 G-Sensor、Compass Sensor，其中 GPS Log-frequency Adapter 會根據目前 GPS Receiver 的記錄頻率、Bicycle Route Database 對路徑特徵的判斷與 G-Sensor、Compass Sensor 的移動感測來調整接下來的 GPS 記錄頻率。但是自行車移動狀態的變動十分頻繁，因此我們將自行車騎士之移動模式分成為四類，設計了 Normal Mode 與 Lazy Mode 兩種模式，避免因為隨機的變動造成不必要的狀態轉換。

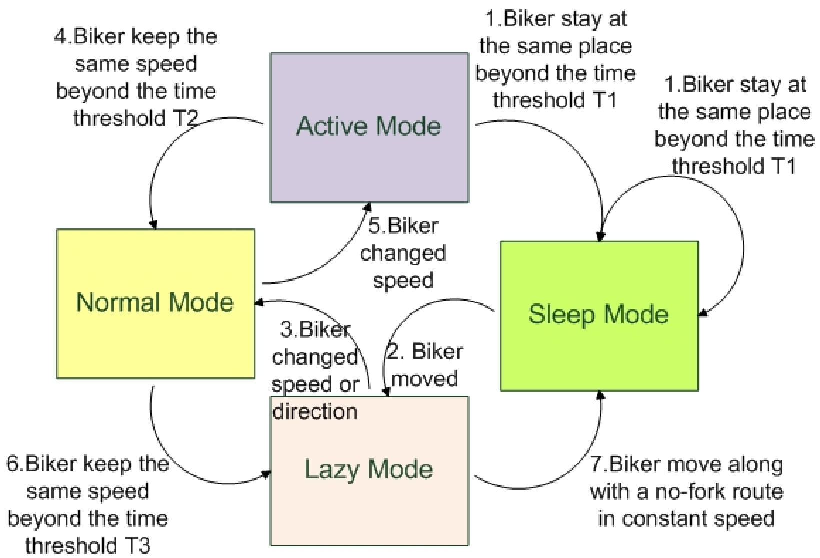


圖5：自行車騎士移動模式圖

GPS Log-frequency Adapter 在不同的移動模式有不同的 GPS 記錄頻率。如圖 5 所示，第一類是 Active Mode：自行車騎士的移動速度變化很大，且有可能會變換未來欲騎乘之路徑；第二類是 Normal Mode：自行車騎士以穩定的速度移動；第三類是 Lazy Mode：自行車在 Normal Mode 停留一段較長的時間；第四類是 Sleep Mode：自行車騎士靜止不動，或是可以根據目前的速度與自行車道資料庫推估未來某一時間點的位置。這四種不同的移動模式 GPS 記錄頻率由大到小為 Active Mode＞Normal Mode＞Lazy Mode＞Sleep Mode，我們根據文獻[18]來設定在自行車騎乘的環境下這四個模式的定位頻率分別為 F_{Active} = 1Hz、F_{Normal} = 0.2Hz、F_{Lazy} = 0.02Hz、以及 F_{Sleep} = 0Hz，並且設計了一個動態的 GPS 記錄頻率調整機制，藉由偵測目前的移動模式與位置，切換 GPS 記錄頻率，儘量減少電能消耗又不會漏失重要的位置變化記錄。

我們利用程式模擬自行車騎乘環境評估效能，假設以 Active Mode 作為起始狀態，此時預設接收 GPS 定位訊號頻率為 1 Hz。當自行車騎士靜止時，持續地接收 GPS 定位訊號是沒有幫助的。假設當自行車騎士等待長時間的紅燈或者是在景點停留，**1.** 休息超過某個給定的時間閥值 T1 後(T1=20 秒)，就讓 GPS 定位系統進入 Sleep Mode 停止接收 GPS 訊號，減少電能消耗，**2.**此時系統會開啟加速度計偵測自行車是否開始移動，如果開始移動後則會進入 Lazy Mode 以F_{Lazy}的頻率來接收 GPS 訊號，**3**.如果速度或方向有變動，則會由 Lazy Mode 進入 Normal Mode，提高接收 GPS 訊號的頻率至 F_{Normal}。另一方面，**4.**如果自行車騎士以勻速前進超過時間閥值 T2 (T2=25 秒)後，會從 Active Mode 轉換至 Normal Mode，可以使用較低的定位記錄頻率F_{Normal}，**5.**假如在時間閥值內自行車改變了速度，則由 Normal Mode 回到 Active Mode。**6.** 當騎士維持 Normal Mode 超過時間閥值 T3 (T3=30 秒)後才進入 Lazy Mode，以更低的頻率 F_{Lazyl} 來接收 GPS 訊號。搭配自行車車道路線資料庫(Bicycle Route Database)與 G-Sensor、 Compass Sensor，當確定 **7.**.騎士沿著沒有岔路的車道上勻速前進後進入 Sleep Mode。在進入 Sleep Mode 後關閉 GPS，改為開啟 G-Sensor 與 Compass Sensor，以維持定位精度，避免因為 GPS Sleep 太長時間而漏失重要的位置變化記錄。如圖 6 所示，充滿電的電池電量為 1340 mAh，GPS receiver 之電流消耗為 30 uA，G-Sensor、Compass Sensor 之電流消耗為 5 uA 採用省電演算法之後的手機電池使用時間延長了約 2.23 倍。

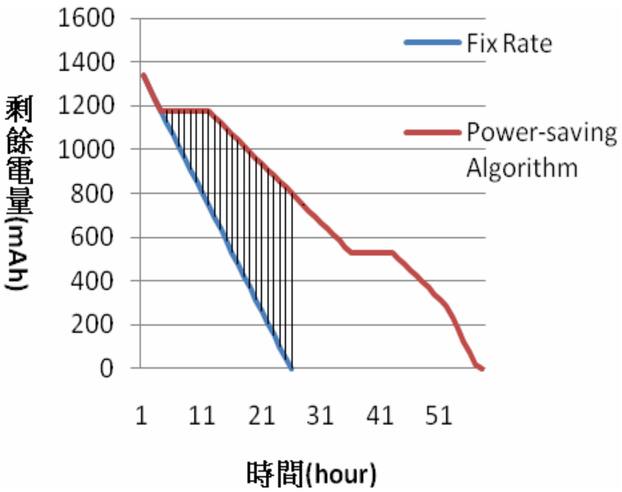


圖6：電力消耗比較(只考慮GPS與Sensor電能消耗)

FUNCTION Start_Active_Mode() **BEGIN** GPS_log in defaultFrequency = 1 Hz Time_counter = 0 DETERMINE the biker stayed or moved BY GPS signals Time_counter++ **IF** Time_counter > T2 THEN goto Normal Mode **ELSE IF** Time_counter > T1 THEN goto Sleep Mode **ELSE** wait,check again **END**	**FUNCTIO**N Lazy_Mode() **BEGIN** GPS_log in lazyFrequency Time_counter = 0 DETERMINE the biker's route have fork path or not BY route Database **IF** the biker's route have no fork path **THEN** goto Sleep Mode **ELSE IF** move Sensor **THEN** goto Normal Mode **ELSE** wait,check again **END**
FUNCTION Normal_Mode() **BEGIN** Time_counter = 0 GPS_log in normalFrequency DETERMINE the biker stayed or moved BY GPS signals Time_counter++ **IF** Time_counter > T3 goto Lazy Mode **ELSE IF** the biker speed up goto Active Mode **ELS**E wait ,check again **END**	**FUNCTIO**N Sleep_Mode() **BEGIN** GPS_log turn off Time_counter = 0 DETERMINE the biker's move or stay **IF** moved **THEN** goto Lazy Mode, **ELS**E stay in Sleep Mode wait check again **END**

圖7：**省電演算法Pseudo code**

4 雛型系統實作

在接下來這一節裡，主要呈現技術與應用服務的實作結果。Android中所支援的基本的GPS定位，採用NMEA 0183的定位格式。當GPS 接收器定位後，便以NMEA 0183資料格式開始傳送有效的定位資料，一般這些資料包含有：(1)經度(2)緯度(3)定位狀態代碼(4)採用有效的衛星顆數(5)高度(6)日期(7)衛星狀態及接收狀態完整的NMEA輸出格式大概有七十餘種，但一般接收器較常使用之格式為：(1)定位資訊(GGA)、(2)基本地理位置–經度及緯度(GLL)、(3)衛星幾何精度因子及衛星狀態(GSA)、(4)GNSS 天空範圍內的衛星(GSV)、(5)基本定位資訊(RMC)、(6)對地位移方向及對地位移速度(VIG)。

4.1 會員系統

如圖 8 所示，會員系統透過會員之間的互動來達成分享彼此旅遊記錄的目的，會員註冊成功就可以分享與搜尋公開或者是好友的資料。

圖**8：LOHAS BikeLog**會員系統登入**/ Facebook**登入

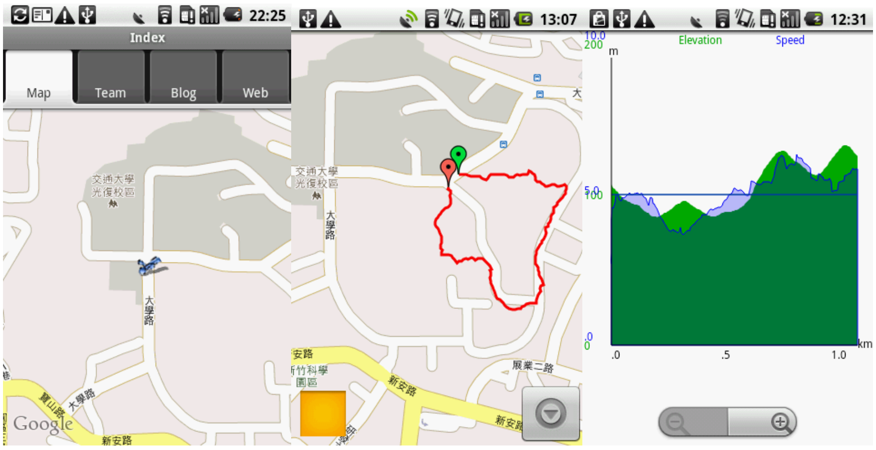
4.2 旅遊記錄

a. Server 端：如圖 9 照相並可上傳至 LOHAS BikeLog 網站。

圖**9**：照片上傳至**LOHAS BikeLog**

b. Client 端：

如圖10(a)進入主畫面，在Map分頁的地圖中顯示了一個藍色人型標記，代表目前手機的實際位置在地圖上的的對應；另外人型標記會隨電子羅盤的數值而旋轉，因此人型標記的頭部總是指向手機持有者所面對的方位。(註：地圖的正上方永遠為地理北極)。地圖正下方的+號與-號按鈕，分別可以放大地圖的顯示層級與縮小的圖的顯示層級。如圖10(b)根據GPS路徑資訊，畫出距離對高度的折線圖如圖10(c)，變化率即是坡度。



(a) (b) (c)

圖 10：選取記錄 Track 的模式/坡度折線圖

如圖11在Blog分頁中，可用語音辨識的型式輸入文字訊息並發佈至LOHAS BikeLog部落格或Facebook

圖 11：語音辨識輸入/語音轉換成文字

如圖 12 若選擇照相功能則可可選擇上傳至 Facebook

圖 **12**：手機照相功能/上傳至 **Facebook**

c. 旅遊紀錄查詢(照片，路徑)：如圖 13 可查閱之前行動裝置所傳過來的照片以及路徑，並可以以折線來表現出會員的路徑。

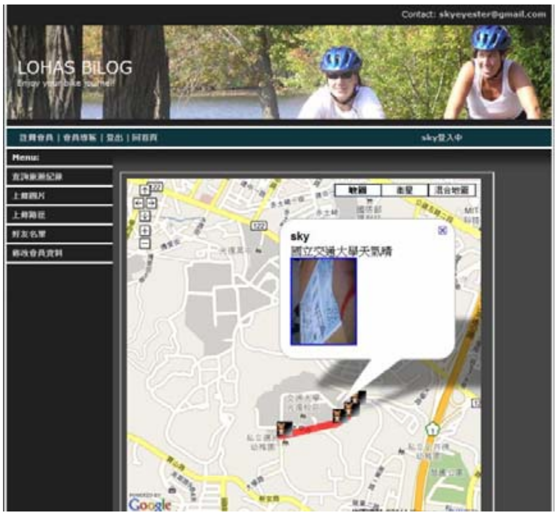


圖 **13**：查詢旅遊紀錄

4.3 充電裝置

如圖 14(a)為自行車與手機的實際裝置情形，如圖 14(b)為裝載於自行車上之手機與充電裝置實際連接情形。如圖 15 為充電裝置安裝於自行車上之情形。

圖 **14**：手機裝置於腳踏車上/手機連接充電裝置

圖 **15**：充電裝置安裝於腳踏車上

我們將坡度的資訊與數位地圖結合，經過上坡與下坡路徑與皆會向使用者發出提示，如圖 16 開啟預設路徑模式後，可顯示接下來要通過的路段是上坡以判斷是否進行充電動作。

圖 **16**：上坡通知

5 結論

在本論文中，我們結合智慧型手機與位置感知服務，設計並實作了一個自動化的自行車旅遊紀錄系統 LOHAS BikeTel，使得自行車騎士可以利用語音辨識，將口述心得轉成文字上傳至部落格或網誌，或者是將旅途中的拍攝照片、經過的路徑資訊上傳至系統中分享給朋友，更進一步，利用路徑資訊動態調整 GPS 使用來減少電能消耗，也利用坡度資訊對手機電池進行充電。本系統設計了 GPS 的省電演算法，並提供了騎士間新型的社群資訊交流平台。

6 誌謝

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

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摘要

在本篇論文中，我們提出了在道路上的每台車輛均配備了影像攝影機並結合車牌辨識技術來識別可疑車輛(例如贓車)，以及利用車載無線通訊介面與車間通訊方式來協同追蹤可疑車輛和快速回報此發現給附近的警車。我們設計的機制不需要任何路側基礎設施之輔助，主要元件為追蹤模組與回報模組，追蹤模組在必要時可將追蹤任務換手至鄰車以持續追蹤可疑車輛，並可不依賴數位地圖而偵測出交叉路口的存在；回報模組則可在所偵測出的交叉路口利用協同式路口導引方式來回報可疑車輛之最新位置至附近警車。模擬實驗結果顯示我們所提出之方法可有效地避免重廣播不必要的訊息，並可大量地節省網路上廣播訊息的頻寬使用。除此之外，我們還設計並實作出一個新型車載監視與感測系統，整合了各式感測裝置、無線通訊技術與車間通訊功能，以達成車輛追蹤與回報的目的。

關鍵詞：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。

一、前言

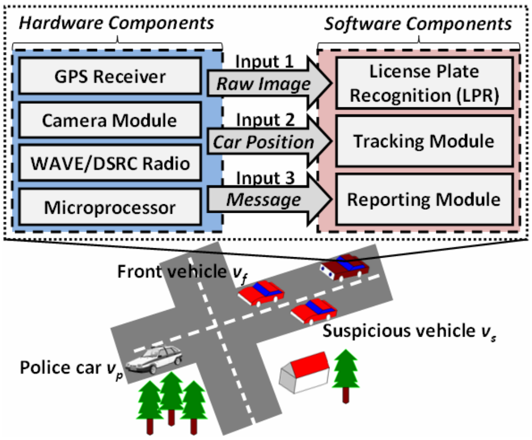
隨著車載無線存取/特定短距通訊標準(Wireless Access in Vehicular Environments /Dedicated Short Range Communications, WAVE/DSRC)和嵌入式監視系統技術的快速發展，車輛可配備車上通訊裝置與影像攝影機來監控發生在道路上的各種事件，其應用包括車輛安全[1]、煞車示警[2]和市區監控[3]等。本篇論文的目標是追蹤可疑車輛並回報至附近的警車，而且無需依賴高成本的基礎建設。現有研究成果針對車輛追蹤與回報這兩個目的往往都需要依賴佈建大量的路旁基礎建設與感測器來實現[4–8]。

在以車輛追蹤為目的之相關研究成果中，文獻[4]利用無線感測技術設計出一個車載追蹤系統架構，其中路旁基礎設備(Road Side Units, RSUs)被設置在沿途的道路上，並週期性不間斷地追蹤道路上的車輛。此外，這些RSUs通常會透過有線網路連接後端的基礎設施，接收來自於中控伺服器的查詢以及回應必要的相關資訊。文獻[5]設計以無線區域網路(Wireless Local Area Network, WLAN)為基礎的即時車載定位系統，提出的解決方案是使用類神經網路搭配數位地圖資訊，並以車輛附近 WLAN 存取點(Access Points, APs)的接收訊號強度為特徵值，做定位訊號樣本空間的比對訓練，使其達成車載定位與追蹤的功能。

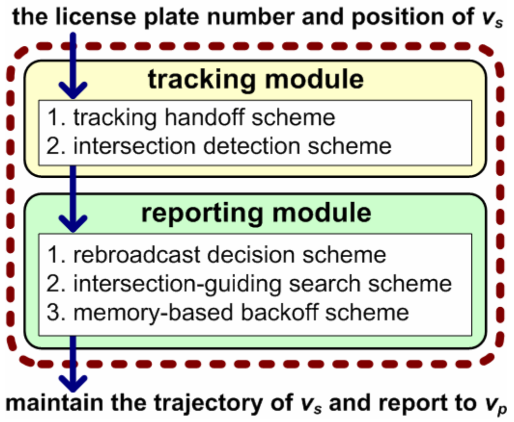
然而，在這兩篇文獻所提的內容中，都必須在道路旁安裝大量的 RSUs 和 WLAN APs 來分別提供目標車輛資訊和接收來自目標車輛的訊號。文獻[6]在車載隨意網路(Vehicular Ad Hoc Netowrks, VANETs)環境中提出一個智慧型停車系統，其中包含了贓車追蹤機制，當竊賊沿著道路行駛贓車期間，路途中所經過的RSUs可以偵測到來自於贓車所發出的停車訊號(Parking Beacon)，並可根據 Beacon 中夾帶的停車場識別碼回報贓車目前的位置到停車場處理中心。但是，如同文獻[4]和文獻[5]，這類的處理機制都需要沿著道路上大量佈建RSUs 來達成贓車的追蹤。

另一方面，在以回報為目的之相關研究成果中，文獻[7]提出一個 ANTS 機制來尋找靠近於查詢者的特定車輛，此機制已經使用在文獻[8]之中，ANTS 尋找方式主要是基於觀察迷路螞蟻會用目前位置為起點以螺旋狀路徑來尋找巢穴的現象，透過在路口設置大量的區域節點(Local Nodes)，負責紀錄車輛往來資訊和接受來自車輛的查詢訊息。然而，在路口佈建 Local Nodes 需要使用大量的 RFID Readers 和 WLAN APs，會造成佈建上鉅額的成本開銷，更重要的是在郊外與鄉村地區建置 Local Nodes 是不符合成本效益的。

因此，我們針對可疑車輛追蹤與回報提出無需基礎設施的解決方案(Infrastructure-less Framework)，此 Framework 包括了追蹤模組(Tracking Module)與回報模組(Reporting Module)。在追蹤模組的機制設計中，可在必要時將追蹤任務換手至鄰近車輛以持續追蹤可疑車輛，並可不依賴數位地圖而偵測出交叉路口的存在；而回報模組的機制設計則是可在所偵測出的交叉路口利用協同式路口導引方式來回報可疑車輛之最新位置至附近警車。



圖一、可疑車輛追蹤與回報系統架構



圖二、可疑車輛追蹤模組與回報模組

除此之外，由於傳統監控和追蹤系統必須藉由設置於路旁攝影機設備的影像記錄來實現其監控功能，但是這樣的方式存在著兩個問題，第一，它需要花費較多時間與心力來從大量的影像記錄中識別出特定車輛；第二，一般來說，由於特定車輛並非可事先設定，因此所紀錄到的相關影像記錄通常不夠清晰，更甚者，影像記錄的數量隨著時間日益龐大，將進一步造成人力成本的提升。在本篇論文中，我們將以車間(Vehicle-to-Vehicle, V2V)通訊為基礎來設計並實作出無需依賴路旁基礎設施的可疑車輛追蹤與回報系統，以進一步克服傳統監控和追蹤系統的缺點。

二、系統設計

圖一顯示我們所提出可疑車輛追蹤與回報的系統架構，行駛於道路上的車輛可藉由 V2V 通訊來形成車載監控網路，每台車輛配備 GPS 接收器和 Video 攝影機，GPS 接收器可讓車輛取得目前的位置資訊，而 Video 攝影機則是用來拍攝位於車輛正前方車輛的車牌影像，藉由車牌辨識(License Plate Recognition, LPR)技術，每台車輛可以即時識別出位於它正前方車輛的車牌號碼。此外，車輛上將建立一個可疑車輛資料庫(Suspicious Vehicle Database)，此資料庫的內容可事先從警政單位下載或即時透過車間通訊更新。車輛行駛於道路的期間，對於可疑車輛之判別可藉由所識別出車牌號碼與資料庫中可疑車號的比對來得知。

在車間通訊功能方面，每台車輛裝備有支援 IEEE 802.11p 無線通訊介面[9]，其通訊模式設定在車載無線存取(Wireless Access in Vehicular Environments, WAVE)模式，WAVE 模式可簡化車間通訊的關聯(Association)和認證(Authentication)程序以減少連線建立的時間。只要兩台車輛設定在相同的無線頻道(Channel)，並且使用萬用基本服務組合 ID (Wildcard Basic Service Set Identification)，即 48-bit 長度欄位全被設定為 1，任兩台在道路上相遇的車輛便可立即通訊，無須執行加入基本服務組合的程序。我們假設行駛於道路上的車輛均週期性地廣播 Beacon，每台車輛可藉由所接收之 Beacon 獲得通訊範圍內鄰近車輛的位置分佈。此外，訊息有效期間(Time to Live, TTL)也包含於 Beacon 中以限制車載網路的訊息廣播範圍。

在本篇論文中，我們對於可疑車輛追蹤與回報的問題定義如下，每個無線通訊介面的通訊範圍為 R，每一台車輛 i 持續識別其正前方的車輛 v_f 是否為可疑車輛 v_s。我們的目標是設計出高效率的機制來協同式追蹤已被識別的 v_s，並在追蹤期間於每個經過的交叉路口來回報 v_s 最新的位置給 v_p，回報訊息 m_r 是以多節點(Multi-hop)傳送方式導引至附近的 v_p，當 v_p 接收到 m_r 後，便可重建 v_s 的移動軌跡，以及儘快抵達 v_s 所在位置以採取必要的處理措施，以下是我們所設計之可疑車輛追蹤與回報機制的目標：

- 追蹤工作換手(Tracking Handoff)：車道改變或路口轉向時可將追蹤工作換手至鄰近車輛以持續追蹤 v_s。
- 交叉路口偵測(Intersection Detection)：無需數位地圖輔助即可偵測出所經過的交叉路口以回報 v_s 最新位置給 v_p。
- 位置回報廣播(Location Reporting)：根據鄰近車輛位置分佈來設計 v_s 位置回報方式以減少 m_r 的重廣播數量。
- 回報訊息導引(Message Guiding)：根據 v_p 所經過之位置來將 m_r 導引至最近的 v_p 以減少位置回報的訊息負擔(Overhead)。

三、可疑車輛追蹤與回報

如圖二所示，我們針對可疑車輛追蹤與回報問題提出一個由 Tracking Module 和 Reporting Module 所構成的 Infrastructure-less

表一、符號摘要表

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
d_g	the guiding direction of m_r
N_i	the neighboring vehicles of vehicle i
s_H	the sector with angle θ_H located on the head of a vehicle
s_T	the sector with angle θ_T located on the tail of a vehicle
s_R	the sector with angle θ_R located on the right of a vehicle
s_L	the sector with angle θ_L located on the left of a vehicle
s_C	the corresponding sector for d_r
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 small integer for the first backoff window
ρ	the number of backoff classes
T	the valid duration of the memory for v_p

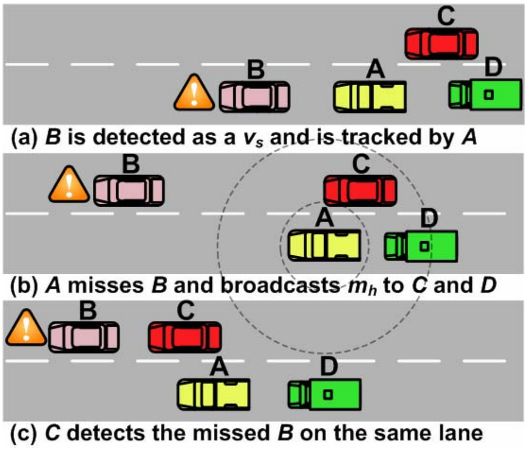
Framework，在 Tracking Module 方面，我們設計了 Tracking Handoff 機制和 Intersection Detection 機制來持續追蹤 v_s；在 Reporting Module 方面，我們設計了 Rebroadcast Decision 機制、Intersection-guiding Search 機制、以及 Memory-based Backoff 機制來有效率地傳送 m_r 至附近的警車 v_p，表一為在本論文中所使用到的符號摘要表。

(一) 追蹤模組

在車載監控網路中，藉由車上所裝備的 Video 攝影機，每台車輛 i 可以對其 v_f 進行拍照的動作，接著以 LPR 技術辨識出其車牌號碼，然後根據經由網際網路下載或附近的警車來建立的贓車資料進行車號比對。當 v_f 被識別為 v_s 後，i 將不斷地進行拍照辨識以持續追蹤 v_s，若 i 或 v_s 改變行駛車道或在路口轉向，透過我們所設計的 Tracking Handoff 機制可立即將追蹤工作換手給鄰近車輛，以達成協同式追蹤 v_s 的目的。除此之外，為了重建 v_s 的移動軌跡以及減少不必要的位置回報，我們還設計一個 Intersection Detection 機制，可在追蹤 v_s 的期間將 v_s 最新經過之交叉路口回報給 v_p。

1) Tracking Handoff Scheme：車輛 i 在一般模式(Normal Mode)和緊急模式(Urgent Mode)將分別以 t_n 和 t_u 秒的間隔來識別 v_f 的車牌號碼，其中 $t_n > t_u$，在 v_f 被識別為 v_s 之前，i 將處於 Normal Mode 來識別 v_f 的車牌號碼，一旦 v_f 被識別為 v_s 後，i 將馬上回報此發現至附近的警車 v_p，並且切換至 Urgent Mode 來識別 v_f 的車牌號碼以持續追蹤 v_s。如果在追蹤期間，由於車道改變或路口轉向的緣故，導致 i 無法繼續追蹤 v_s 時，則 i 將會把追蹤的工作立即換手至其鄰近車輛。

如果當車輛 i 在 Normal Mode 偵測 v_f 為 v_s 時，i 將立即切換成 Urgent Mode 來持續追蹤 v_s。在處於 Urgent Mode 期間，一旦 i 不能夠再偵測到 v_s，i 將立即廣播(Broadcast)一個



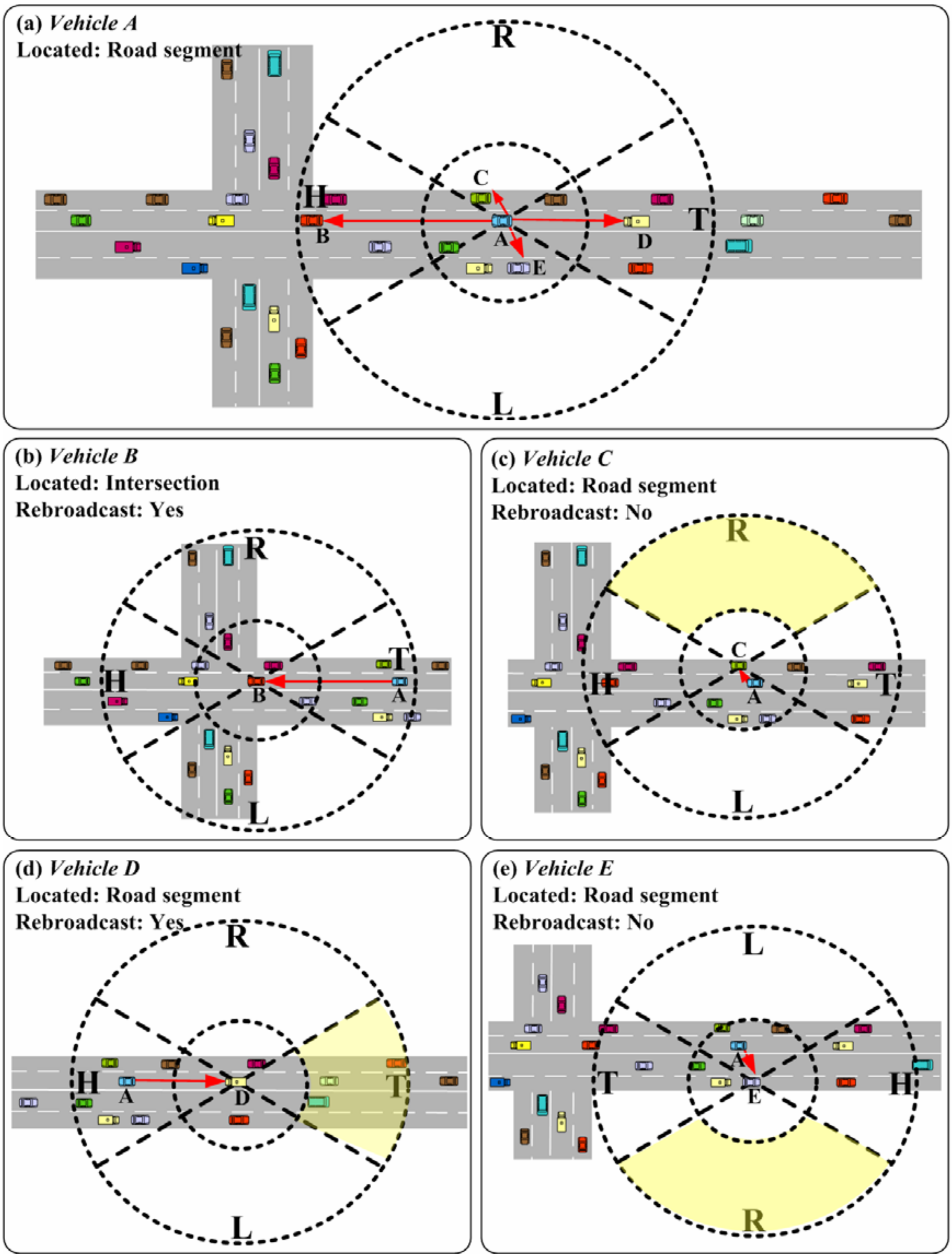
圖三、將追蹤工作換手至鄰近車輛之步驟

追蹤換手訊息 m_h 給鄰近的車輛，當這些車輛接收到 m_h 後，它們將從 Normal Mode 切換成 Urgent Mode 以快速偵測 v_s，一旦鄰近車輛 j 偵測到 v_s 後，便完成來自 i 的追蹤工作換手程序，而其他未偵測到 v_s 的鄰近車輛將在經過事先給定之換手偵測時間後自動從 Urgent Mode 切換回 Normal Mode。同樣地，之後處於 Urgent Mode 的 j 一旦不能偵測到 v_s，j 將重複 i 所做過的追蹤換手步驟。

以圖三為例，A 車目前為正處於 Urgent Mode 來持續追蹤可疑車輛 B，一旦 A 車在 Urgent Mode 不能再偵測到 B 車，A 車將廣播 m_h 給 C 車和 D 車，此時，收到 m_h 的 C 和 D 車為了快速偵測 B 車，將立即從 Normal Mode 切換成 Urgent Mode。一方面，當 C 車已經偵測到 B 車後，此追蹤工作已從 A 車換手至 C 車;另一方面，在經過一段事先給定的換手偵測時間之後，D 車將從 Urgent Mode 切換回 Normal Mode 以減少不必要的偵測工作。

2) Intersection Detection Scheme：如圖四所示，外圈為每台車輛 i 的訊息接受範圍，而內圈是一個可調整參數來過濾鄰近車輛 N_i。根據 i 的行駛方向，我們將把訊息接受範圍分割成四個扇形區域，其分別對應為車頭區域 s_H、車尾區域 s_T、車右區域 s_R 和車左區域 s_L。另外，我們定義 s_H、s_T、s_R、s_L 的角度分別為 θ_H、θ_T、θ_R、θ_L、其中 $\theta_H = \theta_T$、$\theta_R = \theta_L$、$\theta_R = 180\text{-}\theta_H$，而位置處於內圈區域的車輛將不被包含在四個扇形區域中。由於每台車輛會週期性地廣播包含位置資訊的 Beacon 訊息，因此 i 可以獲得在訊息接受範圍內的 N_i 位置分佈，也就可以判斷是否有 N_i 落在 s_H、s_T、s_R 和 s_L 中。除了位置資訊，v_p 也會不斷地宣告它的身份於 Beacon 訊息中。

藉由檢查每個扇形區域是否存在 N_i，i 可以偵測出它自己是否正位於路口(Intersection)或路段(Road Segment)。偵測機制為如果沒有



圖四、以鄰近車輛位置分布為基礎之訊息重廣播機制

任何 N_i 落在 s_R 和 s_L，代表 i 正位於 Road Segment；相反地，如果有 N_i 落在 s_R 或 s_L 其中之一，則代表表示 i 正位於 Intersection。如圖四為例，車輛 A、C、D 和 E 偵測出自己正位於 Road Segment，而車輛 B 偵測出自己正位於 Intersection。

(二) 回報模組

一旦有車輛被識別為 v_s 時，此發現應該立即經由 V2V 通訊來快速回報至附近的警車 v_p，如此一來，附近的 v_p 在接收到回報訊息 m_r 後，便可花費較少時間來抵達 v_s 目前的位置。對於找尋最近的警車 v_p，氾濫式廣播(Flooding)是一個快速直覺的尋找方法，然而，它會產生出較大的網路流量(Network Traffic)，而導致其網路擴縮性(Scalability)較差而無法有效率地使用在大型車載網路中。為了

減少回報 m_r 到附近的警車 v_p 所造成的網路控制訊息負擔(Control Overhead)，我們設計了 Rebroadcast Decision 機制、Intersection-guiding Search 機制和 Memory-based Backoff 機制來有效率地降低 m_r 的重廣播(Rebroadcast)數量。在 m_r 的訊息封包中，包含了發現車輛的 ID、v_s 的位置與其車牌號碼、以及訊息序號(Sequence Number)。

1) Rebroadcast Decision Scheme：在此機制中，車輛會根據自身位置與 m_r 發送者(Sender)位置及其回報方向 d_r 來決定是否要幫忙重新廣播，其詳細步驟如下:

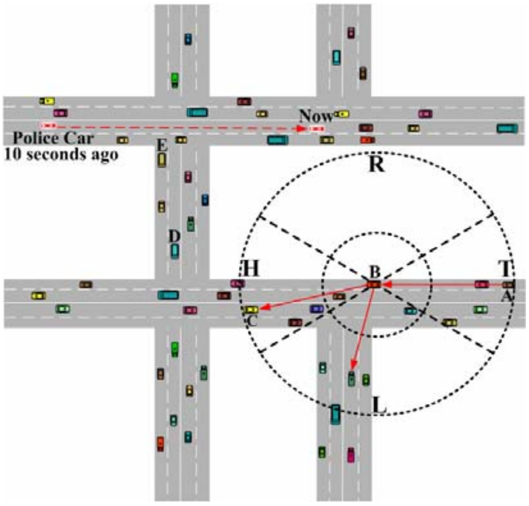
1. 一旦車輛 i 辨識出 v_f 為 v_s，i 將立即發送 m_r 回報此發現給附近的警車 v_p，當車輛 j 收到來自 i 發送的訊息 m_r，j 首先根據 N_j 的位置分佈來偵測目前所在位置型態為路口或路段。

2. 如果 j 目前正位於路口，它將立即幫忙重廣播 m_r;相反地，如果 j 目前正位於路段，它將檢查在 d_r 方向是否有 N_j 位於對應的扇形區域 s_C 中。假如有 N_j 位於 d_r 方向的 s_C，m_r 將被重廣播;否則，m_r 將被忽略以避免不必要的廣播。以圖四(a)為例，由於發送者 A 車落在 B 車的 s_T，因此 d_r 方向為從 j 的 s_T 到 s_H，故在 d_r 方向的 s_C 即為 s_H。

相同地，在其它車輛接收到從 i 發送出的訊息 m_r 後，它們首先偵測目前的位置型態為路口或路段。一方面，位於路口的車輛將廣播 m_r 至所有的扇形區域;另一方面，位於路段的車輛根據在 d_r 方向的 s_C 是否存在鄰近車輛來決定是否廣播 m_r。如圖四為例，基於目前的所在位置和 d_r，而且沒有鄰近車輛落在 C 車和 E 車的 s_R，因此 C 車和 E 車決定不重新廣播 m_r。反之，D 車的 s_T 存在鄰近車輛，因此 D 車決定重新廣播 m_r。

2) Intersection-guiding Search Scheme：基於上述的 Rebroadcast Decisions Scheme，我們更進一步提出一個 Intersection-guiding Search Scheme 來導引 m_r 傳遞至附近的警車 v_p，其處理機制如下所述:

1. 以圖五為例，當 A 車識別其同車道之前方車輛 v_f 為可疑車輛 v_s 後，便會馬上發送一回報訊息 m_r 通知附近的警車 v_p，從 A 車所發出的 m_r 將依序以車間通訊廣播至圖中的四個路口，其中 B 車位於第一個路口，C 車與 D 車位於第二個路口，而 E 車位於第三個路口。



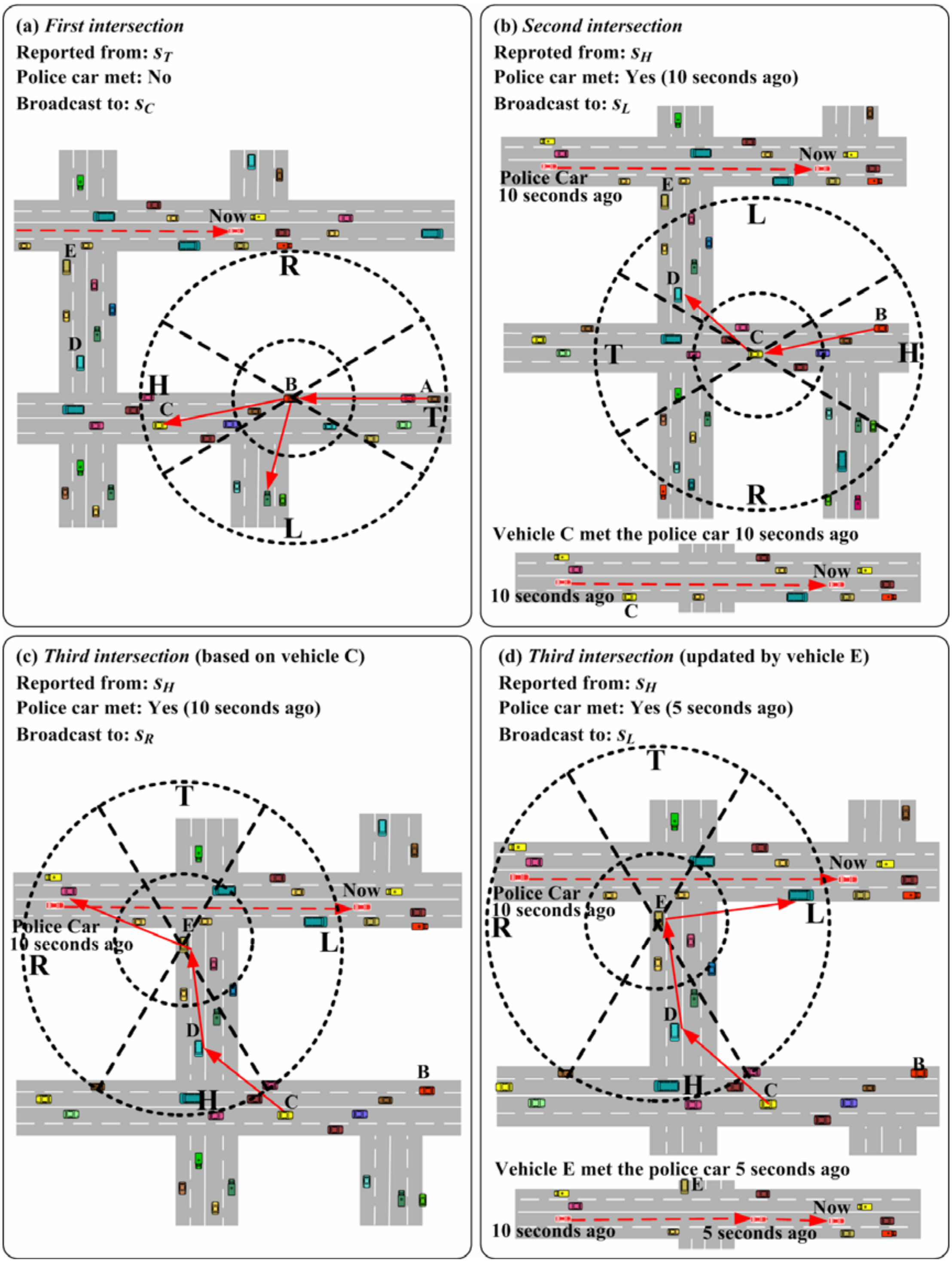
圖五、回報可疑車輛之發現至附近警車

2. 以圖六(a)的第一個路口為例，B 車偵測到 m_r 是來自於 s_T (從 A 車到 B 車)，而且 B 車正位於路口的位置。另外，由於 B 車先前被遇過警車 v_p，所以 B 車決定重廣播 m_r 且不指定導引方向 d_g (即以"Broadcast to: s_C"代替"s_H"、"s_T"、"s_R"、或"s_L")。如此一來，位於第一個路口且接收到來自 B 車重廣播 m_r 的車輛，將自行決定 m_r 的導引方向 d_g。

3. 以圖六(b)的第二個路口為例，C 車偵測到 m_r 是來自於 s_H (從 B 車到 C 車)，而且 C 車正位於路口。由於 C 車在 10 秒前曾遇過警車 v_p，所以根據記憶中 v_p 的位置，C 車將導引 m_r 至其 s_L。如此一來，只有在 C 車的 s_L 區域之鄰近車輛將試著重廣播來至於 C 車輛所發送 m_r。而對於落在其它扇形區域的鄰近車輛，因為 m_r 中 d_g 已經被指定(表示為"Broadcast to: s_L")，故將忽略來自 C 車的 m_r。C 車所指定的導引方向 d_g 是由 C 車目前位置往記憶中警車位置。

4. 以圖六(c)(d)的第三個路口為例，E 車偵測到 m_r 是來自於 s_H (從 D 車到 E 車)，而且 E 車正位於路口，所以根據 C 車對於警車 v_p 的記憶，m_r 應該被重廣播到 E 車的 s_R。然而，E 車在五秒前遇過 v_p，其記憶資訊比 C 車的記憶更新。所以，根據 E 車對警車的記憶，m_r 將被導引更新至 s_L。因此，警車 v_p 可以在下一次的重廣播收到 m_r，而不用將 m_r 重廣播到路口的其他路段。

由於 m_r 可以經由車輛對警車 v_p 的記憶而在路口被導引，重廣播 m_r 的數量將可被有效地減少，同時也能減少由於訊息碰撞(Message Collision)所造成的回報延遲時間，更可避免使用氾濫式廣播造成網路控制訊息的負擔。



圖六、以警車相遇記憶為基礎之路口導引尋找機制

3) Memory-based Backoff Scheme：在 IEEE 802.11p 中，採用原本被提出在 IEEE 802.11e 的 Enhanced Distribution Channel Access (EDCA)機制來分配封包傳輸的優先權[10]，根據不同應用程式之封包特性來選擇不同的通道存取參數，總共分為四種存取類別，分別為 Background (AC_BK)、Best Effort (AC_BE) 、 Video (AC_VI) 、和 Voice (AC_VO)。此外，隨機 Backoff 機制亦被採用於 EDCA，由 Arbitration Interframe Space Number (AIFSN)和 Random Backoff Timer 兩個參數所控制，AIFSN 是一個固定的等待時間，而 Backoff Timer 是根據 Contention Window (CW)來選擇一個隨機的等待時間。CW 的大小一開始被初始化為 CW_{min}，當在傳送期間發生碰撞的情況， CW 的大小將會加倍，直至到達 CW_{max} 為止。表二為 IEEE 802.11p 預設的 EDCA 參數，在我們設計的機

表二、EDCA 預設參數

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

制中，m_r 將使用最小的 AIFSN 來獲得最大的傳送優先權，並隨機選擇一個 Memory-based Backoff Timer 來減少 m_r 的重廣播次數。

當車輛 i 接收 m_r 後，i 首先決定是否要重廣播此 m_r，如果 i 決定要重廣播此 m_r，i 將根據其遇到警車 v_p 之已經過時間 t_i 來決定其 Backoff Timer BT_i。如果 i 之前從未遇到過 v_p，則 t_i 將被設定為∞。因此，當車輛 i 具有較小的 t_i 時，則代表著有較高機會取得較小的 BT_i，其選擇方法如下：

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

τ 為給定之正整數，ρ 為 Backoff Class 的數量，T 為車輛關於 v_p 記憶的最大有效時間。

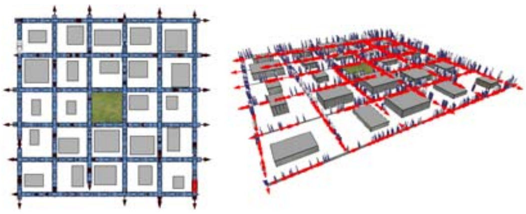
如此一來，當最近遇過 v_p 的車輛在幫忙重廣播 m_r 時，便有較高機率選擇到最小的 Backoff Timer 而成為第一個重廣播 m_r 的導引者。此外，我們更進一步使用 Implicit Inhibition 機制[11]來消除不必要的 m_r 重廣播，當車輛接收到相同 Sequence Number 的 m_r 時，便代表收到 Acknowledgement，則不需要再去幫忙重廣播此 m_r。另一方面，為了避免沒有任何重廣播車輛成功地幫忙廣播 m_r，Sender 車輛的 Backoff Timer 將被設定成 $2^{\tau+\rho}$，一旦 Sender 車輛倒數到 0，則重新傳送一個新 Sequence Number 的 m_r 來與之前的 Acknowledgement 有所區分。

四、效能評估

在本節中，我們使用 QualNet 5.0 網路模擬器[12]並加入必要之修改來作模擬實驗的效能評估，如圖七所示，實驗環境拓樸為 5 km^2 的城市區域，每個街區的大小為 1 km^2。所有車輛都均勻地散布在各個街道上，隨機選擇出

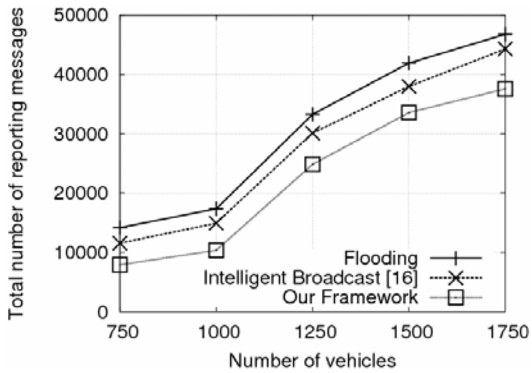
表三、模擬實驗參數

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
Beacon Interval	1 second
Tracking Handoff Timer	10 seconds
Transmission Range	300 m



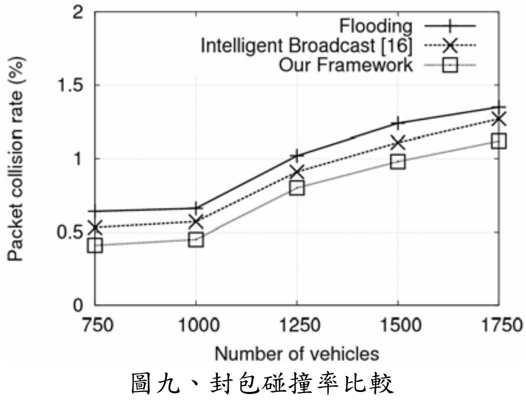
圖七、模擬實驗使用之曼哈頓城市拓樸

一可疑車輛與一警車，每台車輛在路口隨機選擇前進、右轉、左轉三個方向其中之一。表三為我們所使用的模擬實驗參數，並設定 $t_u = 1$ s、$t_n = 10$s、$\theta = 60^{o}$、$\tau = 1$、$\rho = 3$、$T = 30$ s。



圖八、回報訊息之發送數量比較

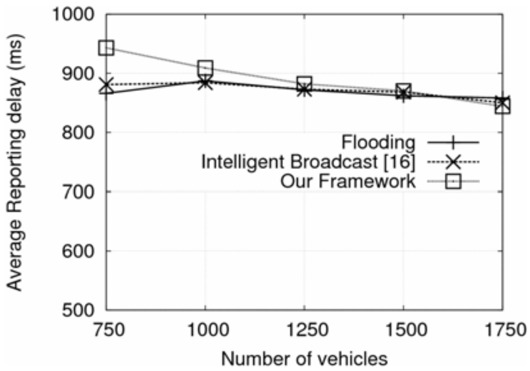
在接下來的效能評估中，我們比較回報訊息的發送數量以及回報至警車的傳輸時間延遲，我們所設計的機制會與氾濫式廣播(Flooding Scheme)和智慧型廣播(Intelligent Broadcast Scheme)[16]做效能比較。圖八為在不同的總車輛數(750、1000、1250、1500、1750)下所測量出的回報訊息發送數量，由圖中可以觀察到我們所提出機制有著較低的回報訊息發送數量，這是由於 Reporting Module 可以有效地根據警車位置的記憶在每一個路口導引回報訊息；相反地，氾濫式廣播與智慧型廣播會在路口的每一個路段重覆廣播回報訊息，所以二者的回報訊息發送數量會隨著總車輛數而增加。



圖九、封包碰撞率比較

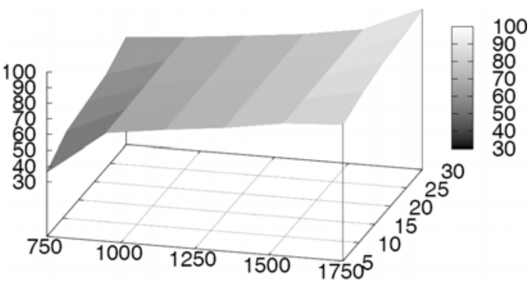
圖九顯示在道路上不同的總車輛數所造

成之封包碰撞率，我們所提出機制相對於氾濫式廣播與智慧型廣播有著較低的封包碰撞率，這是由於氾濫式廣播將重新廣播回報訊息至路口的每個路段，因此導致在同一時間內有較高的傳送封包碰撞率，智慧型廣播亦造成同樣的情形，而且隨著總車輛數的增加，此情形將變得更糟；相反地，我們的方法可有效地導引回報訊息至警車，而且我們提出的 Memory-based Backoff 機制能更進一步地減少封包碰撞率。



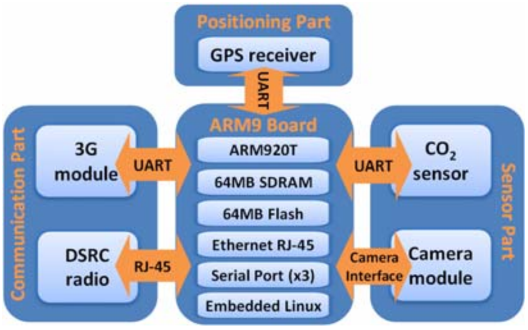
圖十、平均回報延遲時間比較

圖十顯示在不同的總車輛數下，可疑車輛之發現平均回報至警車的平均延遲時間，我們所提出的機制與氾濫式廣播和智慧型廣播隨著車輛數的增加，有著相似的平均回報延遲時間，但可同時保持回報成本較低的優點。另一方面，圖十一顯示在不同的總車輛數與 Tracking Handoff Timer 下所造成的追蹤換手成功率，總車輛數改變量為 750 至 1750 台，Handoff Timer 改變量為 5 至 30 秒，換手成功率隨著總車輛數與 Tracking Handoff Timer 的增加，可從 36%增加至 97%。



圖十一、不同參數設定之追蹤換手成功率

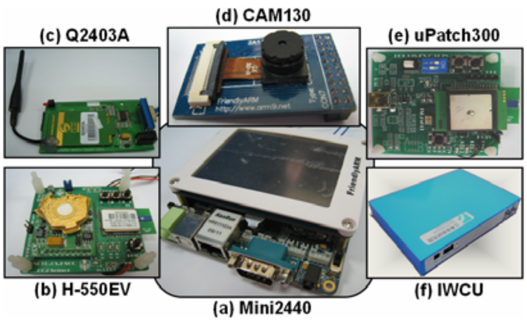
從以上結果可看出我們提出的機制可以達到較低的訊息重廣播次數和封包碰撞率，並可保持與現有方法類似的平均回報延遲時間，能夠更有效率地利用有限的無線頻寬，所以在車載網路中採用我們所提出的機制，可以避免由於不必要的回報訊息重廣播所造成的頻寬浪費，以及避免大量封包傳送而導致回報訊息的碰撞機會。



圖十二、VS[3] 系統元件組成圖

五、雛型系統實作

在本節中，我們設計並實作出一套可疑車輛追蹤與回報雛型系統，命名為車載監視與感測系統(Vehicular Surveillance and Sensing System, VS[3])。圖十二顯示 VS[3] 系統元件組成圖，除了可疑車輛的追蹤與回報功能之外，我們還裝備了 CO_2 感測器和 3G 通訊模組以擴充應用於車輛安全與防盜[1]。Camera 模組和 WAVE/DSRC 通訊裝置，分別以內建的 Camera 傳輸介面和 Ethernet RJ-45 網路介面連接至 ARM 9 開發板，其它的模組則藉由 UART 介面連接至開發板，接下來說明各硬體元件與實作細節。



圖十三、VS[3] 硬體元件

(一) ARM9 開發板

如圖十三(a)所示，ARM 9 開發板是使用 Mini2440 [13]，具備 3.5” TFT 的 LCD 顯示器。Mini2440 配備有 400MHz 32-bit RSIC 整數處理器(ARM920T [14])、64MB SDRAM、64MB Nand Flash、Camera 傳輸介面、三個序列埠、一個 10/100M Ethernet RJ-45 埠和一個內建的麥克風。Mini2440 的作業系統可以安裝 Embedded Linux 或 WinCE 來開發各種應用。我們所使用的 Embedded Linux 開發環境需要先安裝 arm-linux-gcc 編譯器，然後把 ARM9 開發板透過 RS-232 介面連接至 PC 完成 Cross Compiler 環境。

(二) CO_2 感測器

如圖十三(b)所示，我們使用 H-550EV CO_2 感測器[15]整合至 Jennic JN5139 [17]，並透過 UART 介面與 Mini2440 連接，H-550EV CO_2 感測器可達到 0 ~ 5000 ppm 的量測範圍以及±30 ppm 的精確性，JN5139 具備 16MIPs 32-bit RISC 處理器、與 2.4GHz IEEE 802.15.4 相容之無線電收發器、192kB ROM、96kB 的 RAM，還支援 Mesh Networking 和 Packet Routing 的網路功能。為了取得自 CO_2 感測器所偵測到的二氧化碳濃度，我們開啟 Linux 中的 Character Device (例如"/dev/ttySAC#")從序列埠來讀/寫其感測資料。

(三) 3G 模組

如圖十三(c)所示，我們使用 Wavecom Q2403A GSM/GPRS/CDMA 模組連接至 Mini2440，並使用 AT commands 來加以控制。藉由 ARM9 開發板的指令發送來執行 SMS、MMS 和 Video Calls，我們利用 AT commands 控制 GSM/GPRS modem 來完成傳送簡訊的動作。

(四) Camera 模組

如圖十三(d)所示，我們使用 CMOS 光學感測器 CAM130 接收來自 Mini2440 的拍照指令以擷取 Full-resolution 照片，並透過 Camera 傳輸介面把影像資料傳送至 Mini2440。如同 CO_2 感測器，我們開啟 Linux 中的 Character Device (例如"/dev/camera")來取得 CAM130 的原始影像資料。我們使用 Array 來儲存讀取自 Character Device 的資料，並藉由 Linux Frame Buffer 處理機制將擷取到的影像資料複製到對應記憶體空間，使影像內容可以同時顯示在 TFT 螢幕上。

為了將 Camera 模組所擷取到的影像資料輸出成圖檔，我們靜態連結 *libjpeg* 函式庫至可執行程式以將 16-bit color 圖片資料轉換成 24-bit color 格式(RGB888)，並將 16-bit 的 RGB 資料透過顏色補償(Color Compensation)使圖片更清晰。

(五) GPS 接收器

如圖十三(e)所示，我們使用 uPatch300 [18]來獲得 GPS 位置資訊，uPatch300 具有嵌入式的 GPS 天線，遵循 NMEA (National Marine Electronics Association) 0183 協定[19]，並使用高感度 SiRFstarIII 晶片來提供地理位置資訊以完成車輛位置的定位。

(六) WAVE/DSRC 通訊裝置

如圖十三(f)所示，WAVE/DSRC 通訊裝置是使用 ITRI WAVE Communication Unit (IWCU [20])，可直接經由 Ethernet RJ-45 埠連接至 Mini2440，IWCU 具備兩個 IEEE 802.11p 通訊介面和一個 Ethernet 網路埠，Mini2440 可透過標準的 Linux Socket APIs (例如 bind()、sendto()和 recvfrom())來直接傳送 UDP 封包，然後由 IWCU 將 UDP 封包轉為車載通訊環境專用短訊息(WAVE Short Message, WSM [21])。

(七) Prototype 系統展示

我們整合了下列 LPR 相關功能至 VS^3：車牌定位(Plate Localization)、車牌定向和縮放(Plate Orientation and Sizing)、正規化處理(Normalization)和邊緣偵測(Edge Detection)、字元切割(Character Segmentation)和光學字元識別(Optical Character Recognition)，在可疑車輛追蹤和回報雛型系統展示方面，圖十四(a)顯示我們在壓克力模型汽車內對一張車輛的車牌照片進行拍照的動以及車牌辨識的處理，圖十四(b)顯示此車輛已經被識別為可疑車輛，圖十四(c)與圖十四(d)分別顯示 VS^3 安裝於汽車內部以及進行可疑車輛的追蹤。

圖十四、雛型系統展示

六、結論

在本篇論文中，我們整合了嵌入式監視系統技術與 WAVE/DSRC 車間通訊來達成可疑車輛的追蹤與回報，在道路上的車輛可形成一個車載監控網路來追蹤可疑車輛並通報至附近的警車，並且不需要依賴建置成本高昂的路邊基礎設施之協助。我們所設計機制的主要元件為追蹤模組與回報模組，追蹤模組在必要時可將追蹤任務換手至鄰車以持續追蹤可疑車輛，並可不依賴數位地圖而偵測

出交叉路口的存在；回報模組則可在所偵測出的交叉路口利用協同式路口導引方式來回報可疑車輛之最新位置至附近警車。模擬實驗結果顯示我們所提出之方法可有效地避免重廣播不必要的訊息，並可大量地節省網路上廣播訊息的頻寬使用。此外，我們還設計並實作了一個新型的車載監視與感測系統。

七、誌謝

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Eco-Sign: A Load-Based Traffic Light Control System for Environmental Protection with Vehicular Communications

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ABSTRACT

The Eco-Sign system is a traffic light control system for minimizing greenhouse gases emitted by idling vehicles at intersections. Eco-Sign provides the following features: (i) it can notify vehicles to turn on/off their engines based on expected waiting time for green lights at intersections, (ii) it can dynamically adjust traffic light timing to minimize the number of vehicles stopping at an intersection based on vehicle arrival and departure rates, and (iii) it is a fully distributed system in the sense that each intersection can learn its local traffic condition and optimize its traffic sign setting to prevent congestions and thus traffic jams. Eco-Sign thus demonstrates a new traffic light control system for environmental protection.

Categories and Subject Descriptors: C.2.1 [Network Architecture and Design]: Network communications

General Terms: Algorithms, Design, Management

Keywords: Dynamic Traffic Light Control, Environmental Protection, Ignition Control, Vehicular Communications

1. INTRODUCTION

Traffic congestion in modern cities seriously affects the living quality and environments. Vehicles on the roads produce mass air pollution that emits greenhouse gases such as carbon dioxide, hydrocarbons, and nitrogen oxides. Idling vehicles caused by traffic jams and red lights at intersections waste a large amount of fuel and seriously pollute the air. Studies show that the ratio of man-made dioxide emissions from transportation systems is about 30% [1]. Efforts have been made to increase the traffic flows in urban arterial roads [2], to reduce the waiting time at intersections [3], and to navigate vehicles in congested roads [4].

In this paper, we propose a load-based traffic light control system called Eco-Sign, which can help determine the timing of engine ignition at intersections and thus minimize greenhouse gases emitted by idling vehicles at intersections. At an intersection, a *localization unit (LU)* is placed on each road segment before the intersection to help vehicles know where they are. In addition, a *traffic control unit (TCU)* is connected to traffic lights to control their timing. Each vehicle equips with a *vehicle unit (VU)* to receive from LU the IDs of its road segment and TCU. It then controls its engine ignition based on the traffic light timing from TCU.

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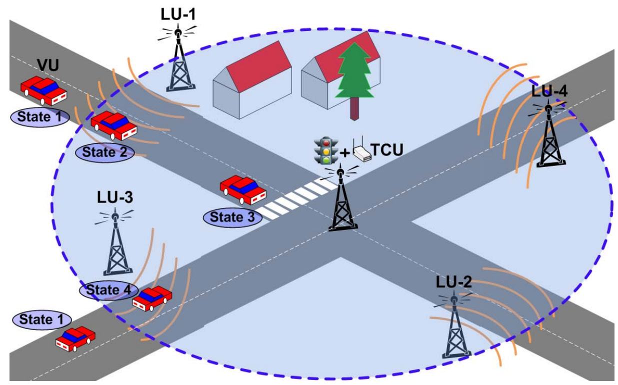


Figure 1: System architecture of Eco-Sign.

In Eco-Sign, a vehicle can get the intersection information from the first passed LU and register itself to TCU as stoping at the intersection. During the registration process, the vehicle will receive the traffic light timing from TCU and its onboard VU can automatically turn off its engine as the remaining waiting time is larger than or equal to a predefined time threshold α. If the engine is turned off by VU, it will be automatically turned on to pass the intersection at the next green light as the remaining waiting time is smaller than or equal to another time threshold β. As passing the second LU at the intersection, VU will deregister itself from TCU. According to vehicle registration and deregistration frequencies, TCU can estimate vehicle arrival and departure rates to achieve dynamic traffic light control.

Eco-Sign can thus help turn on/off engines of vehicles to reduce air pollution as they are waiting at intersections. On the other hand, TCU can dynamically adjust the traffic light timing to minimize the number of vehicles stopping at an intersection based on the observed vehicle arrival and departure rates. It is a fully distributed system in that each intersection can learn its local traffic condition and optimize the traffic sign setting to prevent road congestions. Eco-Sign thus demonstrates a new traffic light control system for environmental protection.

2. SYSTEM DESIGN

Fig. 1 shows the system architecture and vehicles' states at different locations nearby an intersection. On the intersection side, it consists of a LU on each road segment, which provides the location information to vehicles, and a TCU, which decides and transmits the traffic light timing. On the vehicle side, a VU is equipped onboard to receive the traffic light timing from TCU and control the engine ignition timing.

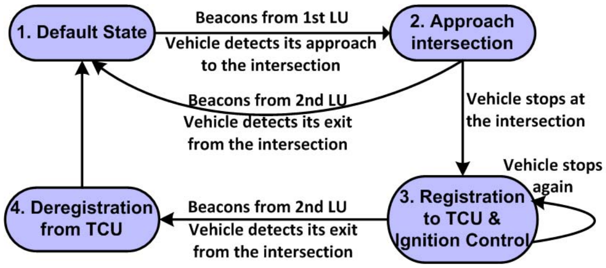
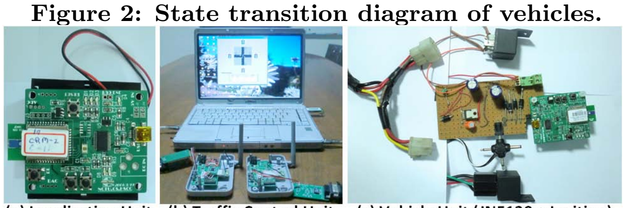


Figure 2: State transition diagram of vehicles.



(a) Localization Unit (b) Traffic Control Unit (c) Vehicle Unit (JN5139 + Ignition)

Figure 3: Eco-Sign hardware components.

VU consists of a network interface, an On Board Diagnostics (OBD) interface [5], an ignition control circuit, and a microprocessor. The network interface is to communicate with LU and TCU. The OBD interface is to capture the current vehicle status. The ignition control circuit is responsible for turning on/off the engine at intersections as its speed is 0 (Alternatively, this can serve as a recommendation service only.). The microprocessor collects information from all other components and issues commands to them. LU is equipped with a directional antenna and is placed at a road segment with a certain distance from the intersection. It periodically broadcasts location beacons on a dedicated channel, which contain IDs of the road segment and TCU, to vehicles entering or exiting the intersection. TCU consists of a microprocessor and two omnidirectional antennas operating in distinct channels, one for vehicle registration and the other for deregistration.

Fig. 2 shows the state transition diagram of vehicles. Initially, a vehicle is in state 1 (Default State). When the vehicle approaches an intersection, it will receive beacons from the first passed LU and then enter state 2 (Approach Intersection). If it passes the intersection without stopping, it will receive beacons from the second passed LU and then switch back to state 1. On the contrary, if it stops at the intersection due to red lights, it will enter state 3 (Registration to TCU & Ignition Control), register itself to TCU, and decide if its engine should be turned off. Note that if it stops at the intersection more than once, it will register itself again and turn off its engine for each stop. When it exits the intersection, it will receive beacons from the second passed LU and then enter state 4 (Deregistration from TCU). After it deregisters itself from TCU, it will go back to state 1.

3. PROTOTYPE IMPLEMENTATION

We have developed a prototype of Eco-Sign. The microprocessor and network interface used in VU, LU, and TCU is Jennic JN5139 [6], which has a 16MIPs 32-bit RISC processor, a 2.4GHz IEEE 802.15.4-compliant transceiver, 192kB of ROM, and 96kB of RAM. As shown in Fig. 3(a), LU is implemented by JN5139 development board powered by four AA batteries. TCU is implemented by integrating two JN5139 development boards connected with a notebook via USB ports, which is running on Windows XP operating system, as shown in Fig. 3(b).

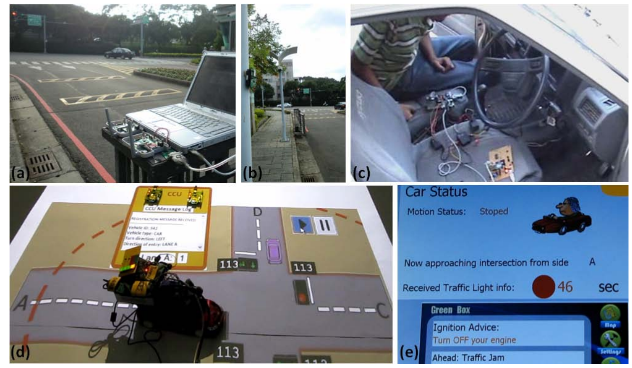


Figure 4: Prototype demonstration.

VU is implemented by JN5139 development board integrated with the ignition control circuit, as shown in Fig. 3(c). The interfacing circuit for ignition control is using ULN2003 [7] Darlington transistor arrays, which takes the signal from Jennic I/O pins and controls 12 V, 40 A automotive relays. A Y-type connector is provided to avoid cutting the original wires inside the car. The power of VU is supplied by the 12 V in-vehicle battery.

Fig. 4 shows the prototype demonstration of Eco-Sign. TCU and LU are installed at the intersection and the roadside lamppost on each direction leading to the intersection, as shown in Fig. 4(a) and Fig. 4(b), respectively. They are operating on 3 different channels. VU is set up in Maruti Suzuki 800 [8], as shown in Fig. 4(c). On one hand, the vehicle is driven from each road segment of the intersection to register/deregister itself to/from TCU. On the other hand, the traffic light timing is varied in road segments of the intersection and the vehicle can receive the correct timing value from TCU. In addition, automatic ignition control is activated as the vehicle speed is 0 km/hr and the remaining waiting time is larger than 30 seconds.

For indoor demonstration, we use a projector to simulate traffic conditions on road segments at an intersection, as shown in Fig. 4(d). A remote control car with VU is used to approach the intersection and trigger operations of Eco-Sign. Fig. 4(e) shows the car status including motion status, approaching side, remaining waiting time, and ignition advice.

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Measuring air quality in city areas by vehicular wireless sensor networks

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ABSTRACT

This paper considers a *micro-climate monitoring* scenario, which usually requires deploying a large number of sensor nodes to capture environmental information. By exploiting *vehicular sensor networks* (*VSNs*), it is possible to equip fewer nodes on cars to achieve fine-grained monitoring. Specifically, when a car is moving, it could conduct measurements at different locations, thus collecting lots of sensing data. To achieve this goal, this paper proposes a VSN architecture to collect and measure air quality for micro-climate monitoring in city areas, where nodes' mobility may be uncontrollable (such as taxis). In the proposed VSN architecture, we address two network-related issues: (1) how to adaptively adjust the reporting rates of mobile nodes to satisfy a target monitoring quality with less communication overhead and (2) how to exploit opportunistic communications to reduce message transmissions. We propose algorithms to solve these two issues and verify their performances by simulations. In addition, we also develop a ZigBee-based prototype to monitor the concentration of carbon dioxide (CO_2) gas in city areas.

1. Introduction

After the industrial revolution, the burning of fossil fuels and many human activities have significantly increased the concentration of carbon dioxide (CO_2) year by year. It is widely concluded that the increase of the CO_2 concentration is a major reason to cause global warming. Therefore, it would be quite interesting to understand how the CO_2 concentration changes over temporal and spatial domains at a very fine-grained size. This is generally related to *micro-climate monitoring*, which intends to collect environmental information in a quite small scale (for example, one measurement per 10 m).

In this paper, we aim at micro-climate monitoring in city areas by using *vehicular sensor networks* (*VSNs*). We consider sensor nodes whose mobility may be uncontrollable (for example, equipping sensor nodes on taxis or buses). Micro-level monitoring usually requires deploying a large number of sensor nodes. However, through mobility, a sensor node can conduct measurements at many different locations, thereby relaxing the demands on the number of sensor nodes. Still, this problem poses several challenges: (1) calibration of sensing data, (2) management and operation of VSNs, and (3) collection and presentation of sensing data.

Among the above challenges, we would like to particularly address two *network-related* issues: (1) how to adaptively adjust the reporting rates of mobile nodes to satisfy a target monitoring quality while reducing the communication overhead and (2) how to exploit opportunistic communications to reduce message transmissions. For example, in a crowded area with many cars carrying sensor nodes, we can reduce the reporting rates of some nodes to reduce possible duplication. On the other hand, at those fields where the CO_2 concentration changes dramatically, a node may need to increase its reporting rate to improve the accuracy. For opportunistic communications, a node may pass its sensing data to a neighbor which is going to submit a report shortly. Also, a node which just arrives at an area may inquire a neighbor (instead of the central server) the required reporting rate inside the area.

We propose a VSN architecture to measure air quality for micro-climate monitoring in city areas, where the CO_2 concentration may change over different regions and the number of mobile nodes could be large. We design two message-efficient algorithms to address issue (1). In particular, the sensing field is divided into regular grids. Each grid can impose its own reporting rate on the nodes within its region. The first algorithm tries to measure the changes of the CO_2 concentration inside a grid and then determine the expected number of reports to be collected within that region. On the other hand, the second algorithm tries to use the changes of the CO_2 concentration and the number of cars inside a grid to determine the expected reporting rate. To address issue (2), we allow a node to collect information and submit reports by taking advantage of its neighbors opportunistically.

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We verify our results through simulations as well as a real prototype. Specifically, we develop a ZigBee-based car network to monitor the CO_2 concentration in Hsinchu City, Taiwan. In our prototype, a car is equipped with a CO_2 sensor, a GPS (global positioning system) receiver, and a GSM (global system for mobile communications) module, which form a ZigBee-based intra-vehicle wireless network. These vehicular nodes roam inside the area of interest and periodically report their sensing data through GSM short messages. These reports are collected by a central server, which shows the monitoring result via Google Maps (2010).

The rest of this paper is organized as follows. Section 2 surveys related work. Section 3 presents the proposed VSN architecture and our algorithms. Section 4 gives our simulation results. Our prototyping results are presented in Section 5. Section 6 concludes this paper.

2. Related work

Wireless sensor networks (*WSNs*) have been widely adopted in surveillance and monitoring applications. For example, He et al. (2006) adopt WSNs to provide a safe and secret way for acquiring information from hostile targets in military surveillance missions. The OceanSense project (Liu et al., 2008) deploys a submarine WSN to collect oceanic data such as temperature and sea depths, while Li and Liu (2007) deploy an underground WSN to monitor coal mines. To forecast volcano eruptions, Werner-Allen et al. (2005, 2006) deploy refractory sensors around active volcanos. WSNs are also deployed to monitor civil infrastructures such as buildings and railway bridges (Xu et al., 2004; Chebrolu et al., 2008). In Wang et al. (2003) and Chebrolu et al. (2007), multi-layer WSNs are proposed to improve the network bandwidth and reduce energy consumption under various surveillance applications. These works all require a large number of static sensor nodes in the sensing field.

Recently, the concept of mobility is introduced to WSNs by dispatching sensor nodes to conduct various missions, such as replacing broken nodes and reacting to the events (Cao et al., 2006; Wang et al., 2010). Such WSNs are usually called *mobile WSNs*. Since sensor nodes are more maneuverable, mobile WSNs have been adopted in vorious surveillance applications. For example, iMouse (Tseng et al., 2007) develops a hybrid WSN consisting of static and mobile sensors for indoor surveillance, where mobile sensors can be dispatched to analyze the abnormal events reported from static sensors. SensorFlock (Allred et al., 2007), an airborne WSN composed of various micro-aerial sensing devices, is designed to analyze toxic plume and storm dynamics to build a three-dimensional view of the atmospheric system. ZebraNet (Juang et al., 2002) is developed to track zebras' migration in Africa, where sensor nodes are equipped on zebras to record their movements and interactions. It can be observed that in the above systems, sensor nodes should be equipped on either specially-made mobile carriers or animals.

Several studies suggest adopting common vehicles such as cars and bicycles as the mobile carriers of sensor nodes to reduce the deployment cost. For example, by equipping multiple types of sensor nodes such as microphones and cameras on bicycles, Eisenman et al. (2009) allow cyclists to help collect road information along some predefined routes. In Kargupta et al. (2004), cars are equipped with vehicular sensors and GPS receivers to conduct car-health monitoring and collect driver habits. In Lee et al. (2006), cameras and chemical sensors on vehicles are used to monitor pollution along streets and vehicles may exchange their monitoring data when they meet each other. In CarTel (Hull et al., 2006), each car is equipped with a GPS receiver to trace its route, a camera to monitor road conditions, and a wireless interface to report data to a central server. These reports can be used for future route planning. Similar to these studies, our work develops a VSN architecture for micro-climate monitoring in city areas. In addition, we address two network-related issues in such an environment. Different from Eisenman et al. (2009), Kargupta et al. (2004), and Hull et al. (2006), we aim at adaptively adjusting the reporting rates of vehicles to balance between the monitoring accuracy and the communication cost. Note that a higher reporting rate improves the monitoring accuracy but incurs a higher message cost (here we adopt GSM short messages), and vice versa. Therefore, our goal is to satisfy a target monitoring quality by minimizing the communication overhead. In addition, we exploit opportunistic communications to aggregate vehicles' reports to further reduce the message cost.

3. VSN-based solutions for micor-climate monitoring

Fig. 1 shows the proposed VSN architecture for micro-climate monitoring. The system consists of some vehicular sensor nodes, a monitoring server, and cellular networks. Each vehicular sensor node (or simply called *vehicular node* or *node*) consists of a central unit and an external unit. The central unit is placed inside the car, while the external unit is attached outside the car so as to collect environmental data. The central unit is connected to a cellular interface (for example, 2G/3G/3.5G), a GPS receiver, and two wireless interfaces. The external unit is connected to a wireless interface and some sensors depending on the application. Here, we consider monitoring CO_2 concentration, so a CO_2 sensor is needed. The central and external units communicate with each other through their

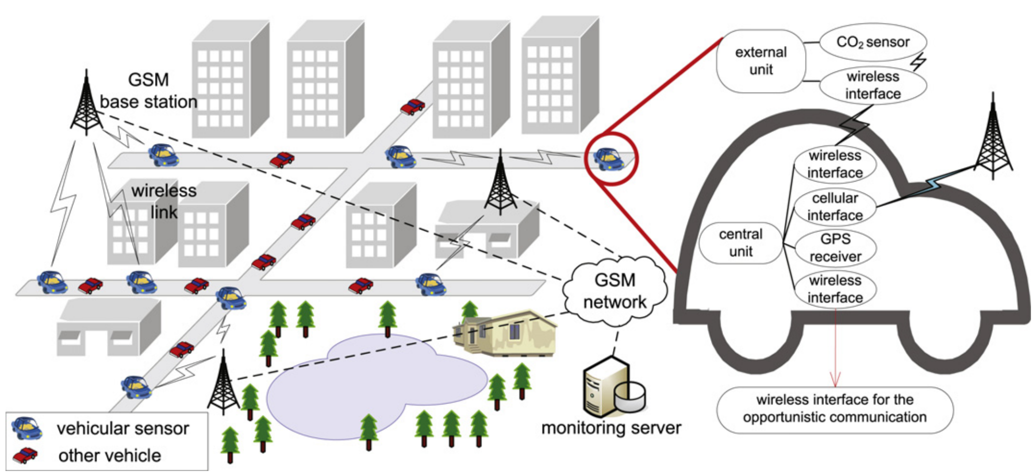

Fig. 1. The proposed VSN architecture for micro-climate monitoring.

wireless interfaces (in this paper we adopt ZigBee). Periodically, the central unit collects the detected CO_2 concentration from the external unit and reports the data, together with its current location, to the monitoring server. The monitoring server then collects all data in each predefined time frame and renders the result on a map (in this paper, we adopt Google Maps (2010).

To reduce the communication overhead, the central unit of a vehicular node can also form an ad hoc network with nearby nodes via their wireless interfaces (for example, Wi-Fi). Such an ad hoc network would allow opportunistic communications among vehicular nodes. Therefore, a node can collect information from its neighbors and help relay other nodes' sensing data to the monitoring server.

In this paper, we consider two network-related issues in the micro-climate monitoring problem. First, since a city area is considered, not only the CO_2 concentration but also the density of vehicular nodes may change dramatically from time to time. Thus, one may need to impose different reporting rates for mobile nodes in different subareas. We call this the *dynamic reporting rate* (*DRR*) *problem*, whose goal is to reduce the communication overhead on the cellular networks while achieving certain monitoring quality. Second, to further reduce the reporting overhead, we consider the possibility of opportunistic communications. When nodes help relay each other's reports, some sort of data aggregation can be achieved. We assume that each report has a deadline by which time it has to be submitted to the server so as to provide timely services. We call this the *time-constrained opportunistic relay* (*TOR*) *problem*.

To achieve our goals, the whole sensing field is partitioned into fixed-size grids $G_1, G_2, \ldots, G_n$. For the DRR problem, the monitoring server will impose a reporting rate r_i on all vehicular nodes in grid G_i, $i=1, \ldots, n$. For the TOR problem, nodes will find out their reporting rates and submit their reports in an opportunistic manner. The monitoring server has a predefined time frame of T seconds. In every T seconds, the server combines all reports that it has collected during that frame and renders the result on a map interface. Below, we present our detailed solutions.

3.1. Solutions to the DRR problem

Since CO_2 concentration is dynamic, we need to determine the expected number of samples to collect from each grid in every time frame based on the record of the previous time frame. The number of samples that we need to collect, however, depends on two factors: (1) the distribution of CO_2 concentration in that area and (2) the number and the distribution of vehicular nodes in that area. Assuming G_i as the target grid, we present two schemes below.

(1) *Variation-based scheme:* Intuitively, a higher reporting rate r_i should be set when the variation of the CO_2 concentration in G_i becomes higher, and vice versa. For example, in Fig. 2, since the CO_2 concentration in grids (2, 4) and (2, 5) fluctuates more quickly than that in other grids, higher reporting rates should be imposed on these two grids. Contrarily, the CO_2 concentration in grids (1, 5) and (2, 6) is more stable, so lower reporting rates could be applied to reduce the amount of transmissions.

From the previous time frame, we can calculate the standard deviation σ_i^{con} of all reported values from G_i and the number of vehicular nodes ν_i that have submitted reports for G_i. We use σ_i^{con} as an index to estimate the number of samples (denoted S_i^{var}) that we expect to receive in the upcoming time frame. We suggest setting S_i^{var} as a linear function of σ_i^{con}:

$$S_i^{var} = a_i^{var} \times \sigma_i^{con} + b_i^{var},$$

where a_i^{var} and b_i^{var} are constants based on the past experience (larger values mean higher monitoring qualities). Note that b_i^{var} indicates the smallest number of reports that we expect to receive. Then, the new reporting rate of G_i can be set to $r_i^{var} = S_i^{var}/\nu_i$.

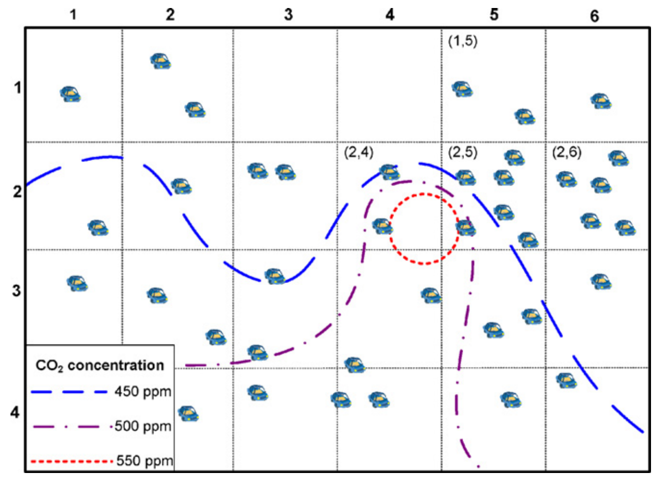

Fig. 2. An example of the reporting rate adjustment.

(2) *Gradient-based scheme:* The previous variation-based scheme has no sense of the locations where samples are collected (that is, two samples collected from different locations of the grid are regarded as the same). For example, for two samples with a fixed amount of concentration difference, if these two samples are taken at very close locations, the change of concentration is regarded as more significant as compared to the case when the two locations farther away from each other. Therefore, the concept of "gradient" can be applied to reflect these factors.

In this scheme, we collect two sets of samples, one consisting of higher values and one consisting of lower values. We then measure the gradients of all pairs of samples between these two sets. Then, the average gradient is adopted to calculate the new reporting rate. Specifically, let R_{high} and R_{low} be the sets of the top γ% and the bottom γ% of the concentration readings in G_i in the previous time frame, respectively. The gradient of two samples $x \in R_{high}$ and $y \in R_{low}$ can be written as

$$\alpha(x, y) = \frac{x - y}{dist(x, y)},$$

where $dist(x, y)$ is the distance of the two locations where x and y are sampled. Then, the average gradient between R_{high} and R_{low} is measured as:

$$\alpha_i^{avg} = \frac{\sum_{x \in R_{high}, y \in R_{low}} \alpha(x, y)}{|R_{high}| \times |R_{low}|}.$$

Similar to the variation-based scheme, the number of samples S_i^{gra} that we expect to receive in the next time frame can be set as a linear function of α_i^{avg}:

$$S_i^{gra} = a_i^{gra} \times \alpha_i^{avg} + b_i^{gra},$$

where a_i^{gra} and b_i^{gra} are constants based on the past experience. Then, the new reporting rate of G_i can be set as $r_i^{gra} = S_i^{gra}/\nu_i$.

3.2. Solutions to the TOR problem

Through opportunistic communications, a vehicular node can help relay others' reports, estimate its own location when it loses the GPS signal, and inquire the reporting rate when it enters a new grid. Our design also includes a randomness mechanism to

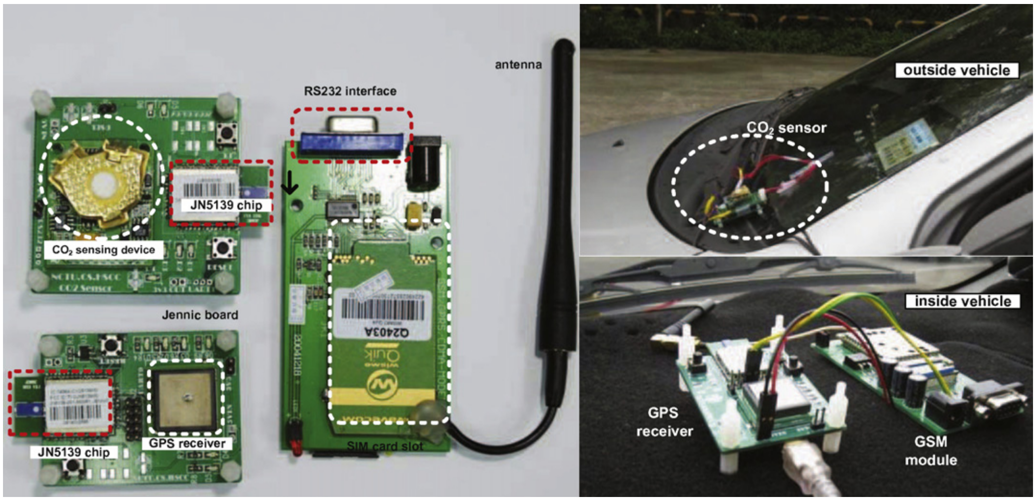

Fig. 3. A snapshot of our prototype.

ensure fairness among nodes when they decide their relaying roles. Note that since GPS is adopted, we assume that nodes are at least roughly time-synchronized. Also, we assume that each node knows the value of T and the due time when the server will render the monitoring result. The details of our solution are listed below:

- Periodically, a node x broadcasts a HELLO packet, through its wireless interface, which contains its current grid ID and its current attraction value att_x, where

$$att_x = rnd_x \times wgt_x,$$

where rnd_x is a random number between 0 and 1 generated by x at the beginning of the current time frame and wgt_x is x's weight variable reflecting the number of sensing reports that x needs to submit to the server so far. Note that wgt_x includes the sensing reports generated by x itself and those that x needs to relay for other nodes.

- When a node does not know the current reporting rate of its current grid after entering a new grid, it first tries to get this information from any neighbor, if possible, through its wireless interface. When the above opportunistic communication is impossible, it then inquires the server through its cellular interface. Then, according to the reporting rate, the node will collect sensing data from its external unit periodically.
- When a node x finds a neighbor y such that $wgt_x < wgt_y$, it tries to send all sensing reports at its hand to y through its wireless interface. On completion of the above operation, x clears wgt_x to zero. On the other hands, y increases its weight wgt_y by wgt_x. If only part of the above process is done before the link between x and y breaks, then these weights are adjusted proportionally. (Note that this step may be extended to multi-hop transmission. However, to reduce complexity and to avoid the ping-pong effect, we choose to only allow one-hop transmission.)
- When x finds that it loses its GPS signal (for example, due to signal blocking), it can estimate its current location through its neighbors' locations. (Note that there are several possibilities (Sheu et al., 2008; Gopakumar and Jocob, 2008) to conduct such an estimation. This is related to localization and is out of the scope of this paper.)
- After the current time frame ends, each node which has a non-zero weight submits all sensing reports at its hand to the server.

The above relaying behavior would allow us to conduct data aggregation to reduce message cost. The reduction ratio is, however, system- and application-dependent. Data aggregation does not affect the measurement accuracy because we assume lossless compression.

4. Simulation results

We develop a simulator in C++ and Matlab to verify the performances of the proposed schemes. Table 1 lists the default parameters in our simulator. Specifically, the monitored region is modeled by a $12.8 \times 12.8\,\text{km}^2$ rectangle, inside which there are 20 horizontal and vertical streets. To simulate a real-road model, vehicular nodes move inside the region following the Manhattan mobility model (Bai et al., 2003), where all nodes move along horizontal or vertical streets. When encountering an intersection, a node determines its moving direction as straight, left turn, and right turn with the probability of 0.5, 0.25, and 0.25, respectively. To keep the total number of vehicular nodes in the region a constant, we do not allow vehicular nodes to move outside the region. Therefore, when a vehicular node reaches the region's boundary, it will turn to an available direction. Vehicular nodes send their reports by GSM short messages. The length of a GSM short message is set to 140 bytes and it costs one dollar. We set frame length T to 600 s.(We will also observe the effect of T in the simulations). The monitored region is divided into 4×4 grids. There are several CO_2 events in this monitored region. The occurrence of CO_2 events follows the Gaussian distribution and each event has a different lifetime. We define the CO_2 event rate as the number of CO_2 events generated every

Table 1
The default parameters of our simulator.

Parameter	Value
Number of streets	20
Area of the monitored region	$12.8 \times 12.8\,\text{km}^2$
Number of grids	16
Number of vehicular nodes	160
Velocity of vehicular nodes	30–60 km/h
CO_2 event rate	$2CO_2$ event
Maximum reporting rate	1/30 report/s
Minimum reporting rate	1/300 report/s
T	600 s
Length of a GSM short message	140 bytes
Cost per GSM short message	1 dollar

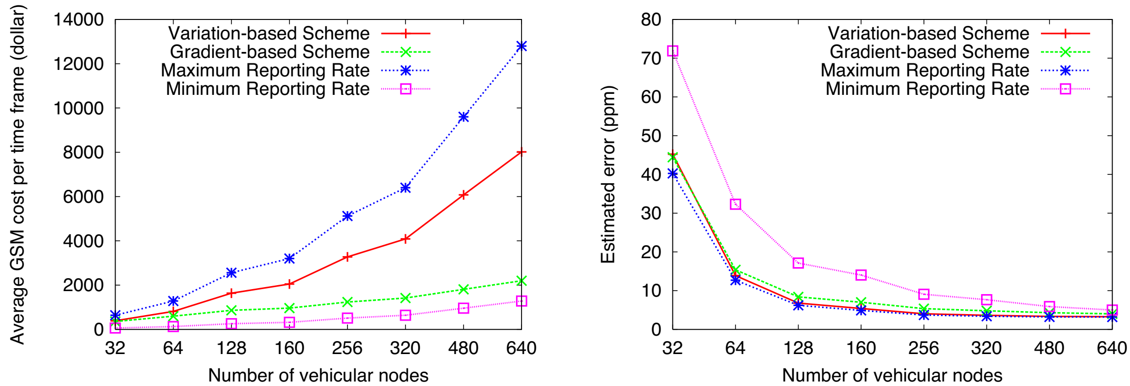

Fig. 4. Comparison of the average GSM short message cost per time frame *T* and the estimated error of CO_2 concentration under different numbers of vehicular nodes.

time frame. We measure the GSM message cost and the estimated error of the CO_2 concentration.

For comparison, we develop two schemes, one using the maximum reporting rate and one using the minimum reporting rate, respectively. Such regular rates are also adopted in Chebrolu et al. (2007) and Juang et al. (2002).

We first observe the effect of different numbers of vehicular nodes on the average GSM message cost per time frame *T* and the estimated error, as shown in Fig. 4. The number of vehicular nodes ranges from 32 to 640. The estimated error is measured by parts per million (ppm). Explicitly, as the GSM message cost increases, the estimated error decreases. Using the maximum reporting rate incurs the highest cost while using the minimum reporting rate incurs the maximum estimated error. Both our variation-based and gradient-based schemes can increase the estimated accuracy while reducing the GSM message cost. The gradient-based scheme can further reduce message transmissions with the expenditure of increasing a small amount of estimated error.

We then observe the effect of vehicular nodes' velocity on the average GSM message cost and the estimated error, as shown in Fig. 5. The velocity range of vehicular nodes are set to [5,25], [35,55], [65,85], [95,115], and [125,145] km/h. It can be observed that this factor has low impact on both GSM message cost and the estimated error. Note that when the node mobility is very low (such as 5-25 km/hr), the benefit of mobility would degrade slightly since a node can only obtain data from nearby locations. In this case, the estimated error will increase.

Fig. 6 shows the impact of the size of the monitored region on the average GSM message cost and the estimated error. The region area ranges from 6.4×6.4 to $102.4 \times 102.4\,km^2$. Changing the region size has almost no effect on the GSM message cost, because the number of vehicular nodes is the same. However, the estimated error increases significantly as the region size increases, because the node density drops fast.

We then vary the number of streets and observe its impact. In Fig. 7, the number of streets ranges from 10 to 100. Changing the number of streets has almost no effect on the GSM message cost because the number of vehicular nodes does not change. When there are very few streets (for example, 10), vehicular nodes can only obtain data from very sparse positions, while results in a higher estimated error.

From Figs. 6 and 7, we can also conclude that node density has the most significant impact on the estimated error.

Fig. 8 shows the effect of different CO_2 event rates on the average GSM message cost and the estimated error. We range the CO_2 event rate from 4 to 24 in every time frame. Because the number of vehicular nodes is constant, changing the CO_2 event rate has almost no effect on the GSM message cost. Interestingly, the GSM message cost of the variation-based scheme suddenly drops when there are 8 CO_2 events. The reason is that the CO_2 event rate in the experiment may not be significant so that smaller reporting rates are set in the variation-based scheme. On the contrary, the CO_2 event rate has significant impact on the estimated error. In particular, since vehicular nodes report almost a constant amount of messages, increasing the CO_2 event rate will result in a higher estimated error. However, both the variation-based and gradient-based schemes can keep quite low estimated errors while reducing the GSM message cost.

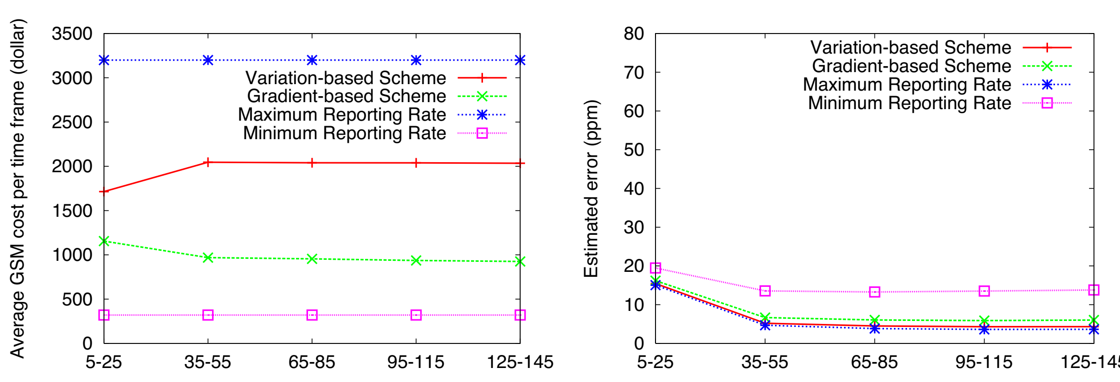

Fig. 5. Comparison of the GSM short message cost per time frame *T* and the estimated error of CO_2 concentration under different velocities of vehicular nodes.

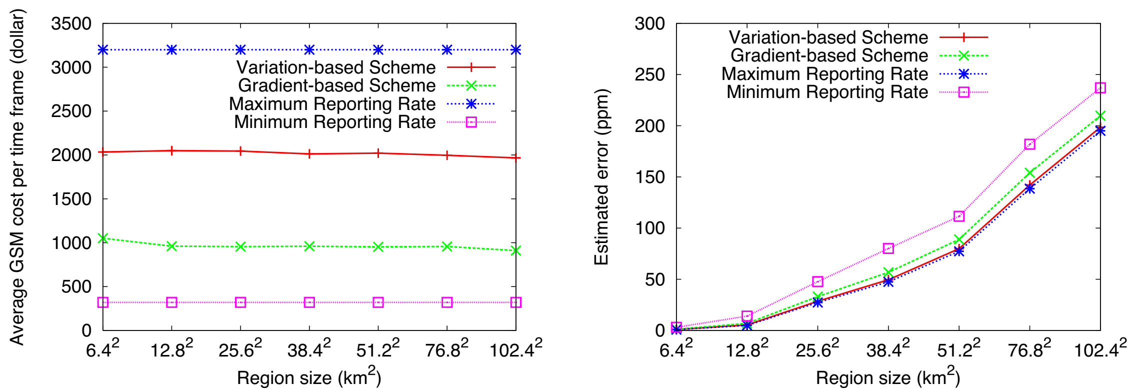

Fig. 6. Comparison of the GSM short message cost per time frame *T* and the estimated error of CO_2 concentration under different sizes of the monitored region.

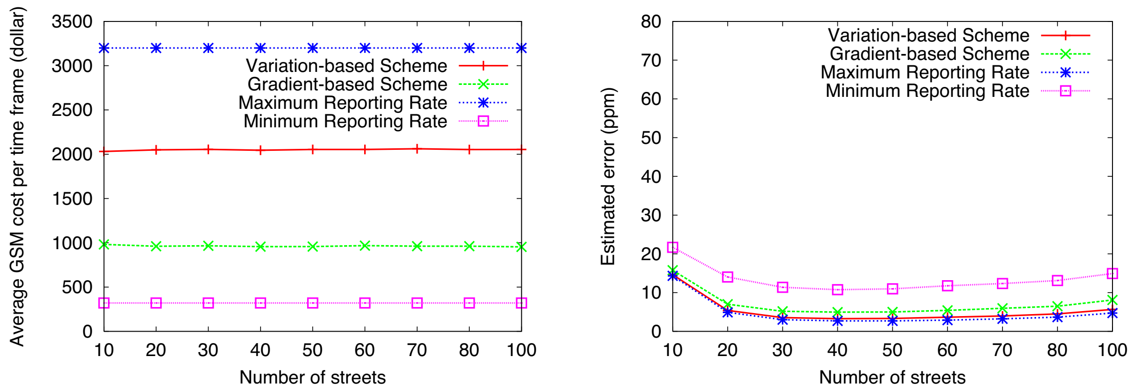

Fig. 7. Comparison of the GSM short message cost per time frame *T* and the estimated error of CO_2 concentration under different numbers of streets.

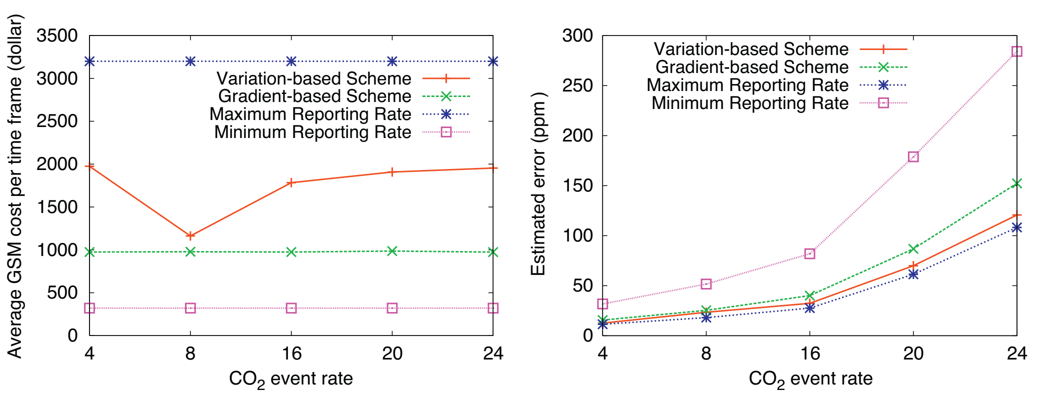

Fig. 8. Comparison of the GSM short message cost per time frame *T* and the estimated error of CO_2 concentration under different variations of CO_2 concentration.

Fig. 9 shows the impact of different time frame length *T* on the average GSM message cost and the estimated error. We vary *T* from 300 to 1050s. As *T* grows, the number of messages per frame increases and the estimated error decreases. For our schemes, the GSM message cost increases less significantly. By using our gradient-based scheme, the increase of the GSM message cost is bounded and the estimated error is reasonable. From Fig. 9, setting *T* to 600 s is a proper choice.

5. Prototyping experiences

We have implemented a prototype of the vehicular sensor node. The hardware components, as shown in Fig. 3 are discussed below.

1. Jennic board: Each Jennic board contains a JN5139 chip (Jennic JN5139, 2008), which has a 32-bit reduced instruction set computing (RISC) processor, a fully-compliant 2.4 GHz IEEE 802.15.4 (IEEE standard for information technology, 2006) transceiver, 192 KB of ROM, and 96 KB of RAM. We adopt the ZigBee protocol (ZigBee specific version, 2006) for inter-board communication.
2. GPS receiver: We adopt the uPatch300 GPS module (uPatch300 module, 2008), which provides geographic location with the maximum tolerant error of 1.8 m. In our prototype, we set the reporting rate to one second.
3. CO_2 sensor: We adopt the H-550EV CO_2 sensor module (H-550EV module, 2008), which samples the CO_2 concentration every three seconds. Its detectable range is from 0 to 5000 ppm with an error range of ±30 ppm. It has response time of 30 s.

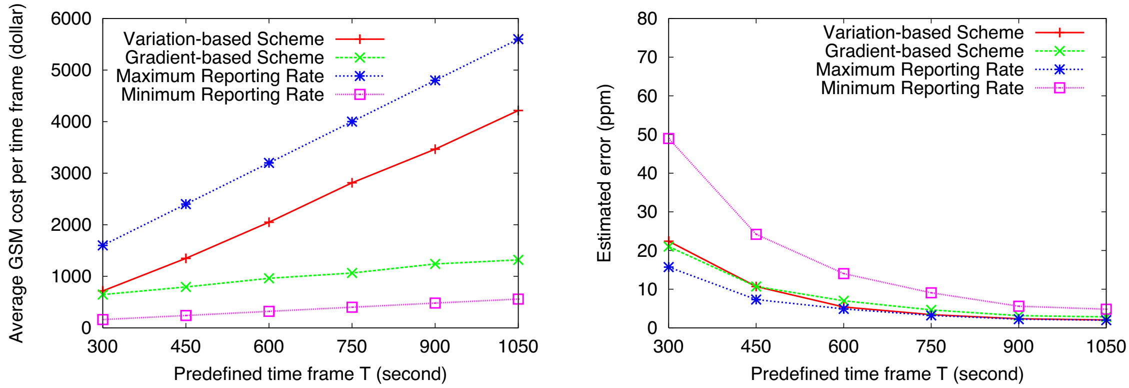

Fig. 9. Comparison of the GSM short message cost per time frame *T* and the estimated error of CO_2 concentration under different time frame *T*.

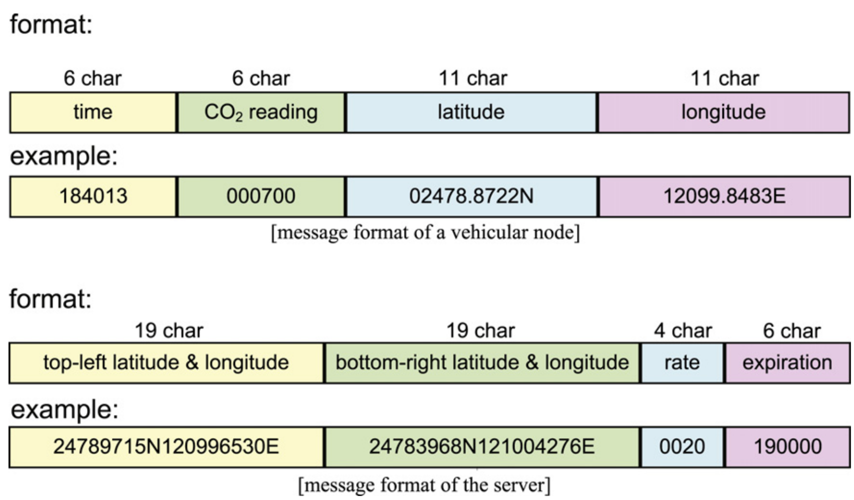

Fig. 10. The formats of our GSM short messages.

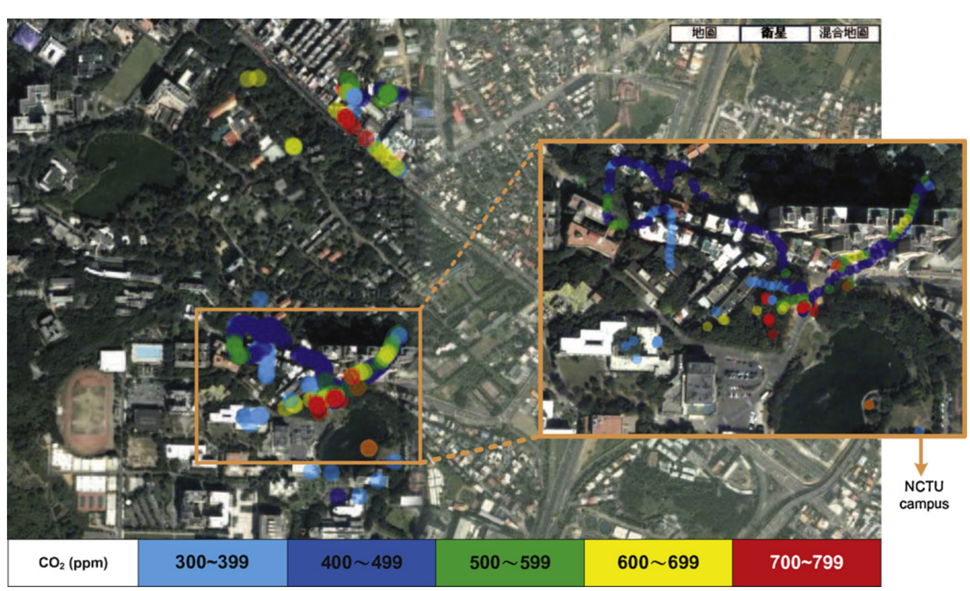

Fig. 11. A snapshot of our user interface.

4. GSM module: We adopt the SIM300 GSM module (SIM300 module, 2008), which supports triband GSM/GPRS communications on 900 MHz, 1800 MHz, and 1900 MHz. It also allows users to transmit GSM short messages.

Fig. 3 shows a snapshots of these components. The CO_2 sensor is installed outside the vehicle, while the GPS receiver and the GSM module are installed inside the vehicle. Each of the GPS receiver and the CO_2 sensor is attached to a Jennic board, so they can communicate with each other through a ZigBee wireless link. The GPS receiver is connected to the GSM module through an RS232 wired interface. The CO_2 sensor reports its readings at a fixed rate to Jennic board inside the vehicle. The Jennic board will then average these readings, combine them with the current location of the vehicle, and report to the monitoring server through GSM short messages. The reporting will follow the requested rate.

Each vehicle reports its current location and monitoring CO_2 concentration through a GSM short message, which follows the format of “time, CO_2 reading, latitude, longitude”, as shown in Fig. 10. For example, a GSM short message of “18401300070002478.8722N12099.8483E” means that a vehicle has detected the CO_2 concentration of 700 ppm at the location of 2478.8722° north latitude and 12099.8483° east longitude at time 18:40:13 (hour:minute:second). On the other hand, the server can adjust the reporting rates of vehicles in certain region by sending a GSM message with the format of “latitude and longitude of the top-left point, latitude and longitude of the bottom-right point, new reporting rate, expiration time”. For example, a GSM short message of “24789715N120996530E24783968N121004276E0020190000” means that the reporting rates of vehicles inside the rectangle with the top-left point at location (2478.9715N, 12099.6530E) and the bottom-right point at location (2440.8565N, 12100.4276E) should be adjusted to 20 times per hour with expiration time of 19:00:00. The message format of the server is shown in Fig. 10.

Fig. 11 demonstrates a small-scale trial in Hsinchu City. We use Google Maps as the user interface in which we use dots with different colors to represent different CO_2 concentration.

6. Conclusions

In this paper, we have proposed a new architecture based on VSNs for micro-climate monitoring. Through GSM short messages and geographic locations of vehicles, we can use a small number of vehicles to realize fine-grained monitoring in city areas. To balance between the monitoring quality and the message cost, we have designed an adaptive approach to adjust the reporting rates of vehicular sensors according to the variance of sensing readings and the number of vehicular sensors in each grid. We have conducted some simulations to validate our proposed schemes, and also demonstrated the prototype of a ZigBee-based intra-vehicle wireless network for the micro-climate monitoring applications.

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Cooperative Localization for Power Saving in Vehicular Long-thin Networks

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***摘要*—本論文提出一個應用於長鏈狀車載網路下的合作式定位機制(Cooperative Localization Framework, CLF)，該長鏈狀車載網路係指沿同一方向移動並具有一領導成員與一移動軌跡之細長形拓樸車隊，車隊成員可以經由無線通訊形成車載網路。CLF 先將車隊成員進行分群(Clustering)，再挑選車隊群組中的特定成員(Anchor)開啟GPS 並廣播含有位置資訊的定位信號，車隊群組中的其他成員(Member)不必開啟 GPS 即可藉由接收定位信號，來計算自己的所在位置。Anchor 與 Member 彼此合作定位可減少整個車隊中開啟的 GPS 裝置數量，以解決位置感知服務(Location-Based Service, LBS)持續定位過程中消耗大量電力的問題，進而延長整個網路的工作時間。**

***關鍵詞*—車載隨意網路、長鏈狀網路、省電、定位、分群**

I. Introduction

近年來位置感知服務(Location-Based Service, LBS)，已成為現代資通訊行動裝置的重要應用，尤其以 iPhone、Android Phone 等智慧型行動手持裝置結合 LBS 服務可以大幅提升這些裝置的使用便利性。另一方面，隨著高油價時代的來臨與健康環保意識的興起，騎乘自行車已經成為國內外的時尚熱潮。例如舉辦各類自行車旅行[1][2]、自行車競技比賽[3]、建立公共自行車租賃系統[4][5]等。將資通訊科技與騎乘自行車的各項活動結合起來，透過手機為自行車騎士提供 LBS 服務，使得自行車旅行更加生動有趣[6]，而且透過 LBS 服務可以讓自行車競技賽事的舉辦與城市中的公共自行車管理更加地方便。由於 LBS 服務的基礎來自於即時與精確的定位，因此在車載無線隨意網路(Vehicular Ad Hoc Network, VANET)與移動式無線隨意網路(Mobile Ad Hoc Network, MANET)領域中有著許多針對網路節點定位方法的相關研究，大致可分為 Network-based System 與 Satellite-based System 兩類[7]，其中以 Network-based System 為基礎有 Time of Arrival (TOA) [8]、Time Difference of Arrival (TDOA) [9][10]、Angle of Arrival (AOA) [11]與 Received Signal Strength (RSS) [12]等定位方法；而以 Satellite-based System 為基礎即為傳統全球衛星定位系統(Global Position System, GPS) [13]。

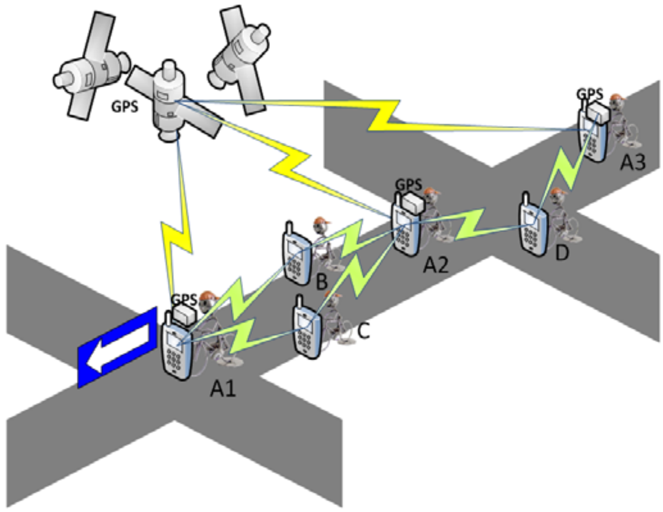
然而，此兩系統在不同的環境下，各有其優點及限制。其中傳統的 TOA 與 TDOA 定位法，在二維座標系中至少需要三個已知位置的參考點才能進行唯一定位，且必須注意系統時間的同步；而 AOA 定位法必須使用高準度指向性天線，因此必須花費較多的硬體成本；傳統的 RSS 定位法需要額外的資料庫系統輔助，甚至需要事前先作環境的資料收集(Training)與誤差調整才能達到一定的準確度；而使用 GPS 全球衛星定位系統雖然不需額外架設基礎設施，但是在較差的天候與地理環境下，由於衛星所發射的信號會被雲層、隧道或其他水泥建築物等阻隔，導致使用 Satellite-based System 定位技術的定位準確度

會下降很多，甚至無法接收訊號進行定位，而且GPS 為一耗電量大的定位裝置，因為行動裝置的電池容量限制，所以同時使用 GPS 定位與Wi-Fi/3G 網路的 LBS 服務將無法持續運作太長的時間，因此在想要持續不間斷地使用 LBS 應用服務的情況下，減少電能消耗以延長行動裝置之工作時間成為一個很重要的議題。

在 GPS 定位省電的研究中，文獻[14]提出了一個簡單以三軸加速度計感測行人移動狀態進行 GPS 定位頻率調整的方法，這個方法雖然可以調整開啟 GPS 的時間，達到省電的目的，但是仍然是以 GPS 為基礎的定位方法，在持續騎乘自行車的情況下，該方法並無法有效地讓 GPS 進入省電模式。文獻[15]除了使用三軸加速度計，還加入了使用者行走的歷史軌跡當作判斷是否開啟 GPS 的依據，但是系統需要事先完成行人移動資料的收集與分析，需要花費比較長的建置時間。文獻[20]必需預先收集使用者資料並進行統計分析，只適合用於規律作息的個人單機 GPS 使用，並不適合用於多人動態成立的自行車隊。雖然以上三種方法都可以節省定位所消耗的電能，但這些方法並未考慮在多成員的網路環境下彼此合作定位。

在本論文中，我們考慮一個自行車的車隊網路成員，具有相同騎乘方向與路線，可透過無線網路進行溝通而形成了一個長鏈狀的車載隨意網路[16]，透過在自行車上裝載 Android 智慧型手機，搭配我們所設計的合作式定位機制 (Cooperative Localization Framework, CLF)可以有效地減少騎乘自行車並使用手機 LBS 服務時的電能消耗，同時仍可以完成所有自行車隊網路成員的定位，且不會漏失關鍵的移動軌跡記錄。

在以下的論文內容中，第二節我們首先描述自行車隊網路的系統架構以及定義此架構的合作式定位問題，第三節接著說明我們所提出的合作式定位解決方案，第四節再討論分析模擬實驗的結果，第五節則提出結論。

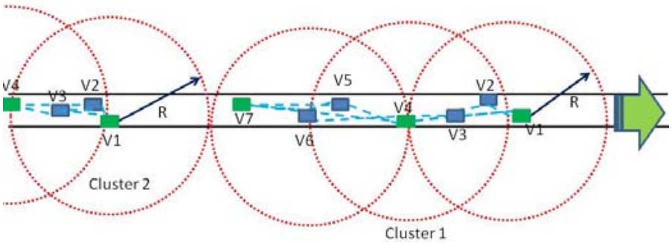


圖一、自行車隊網路架構

II. System Architecture

如圖一所示，本文所探討之合作式車隊定位機制目標為在一個多成員的長鏈狀車隊網路環境下，只需有部分車隊成員 A1、A2 與 A3 擔任 Anchor 開啟 GPS 定位裝置，亦可以使其他擔任 Member 未開啟 GPS 定位裝置的車隊成員 B、C 與 D 都能夠獲得定位。如此一來，可透過減少開啟的 GPS 裝置數量來節省耗電量，並使得電池使用時間增長，進而延長整體車隊網路的工作時間。藉由合作式定位，未開啟 GPS 裝置的 Member 成員仍可以透過與少數開啟 GPS 定位裝置的 Anchor 成員進行通訊來取得位置資訊。

本文所探討之自行車車隊網路架構定義為 $G = (V, E)$，其中 V 為車隊成員所形成的集合，$v \in V$ 為車隊成員網路節點；E 則為兩個車隊成員通訊連線所形成的集合，如果兩個車隊成員在 Ad Hoc 通訊範圍 R 內，則兩者之間存在一條通訊連線 $e \in E$。如圖二所示，整個自行車車隊成員先經由群組形成方法分成兩個群組 Cluster 1 與 Cluster 2，並且選出 Cluster 中的 Anchor 成員 V1、V4 、V6 與 V7。因此在車隊網路中可能會由一個以上的群組所構成，在同一個群組中的車隊成員可以藉由 Wi-Fi 無線通訊來形成 Ad Hoc



圖二、合作式車隊定位機制

Network 進行溝通。並且在同一個群組中的 Member 成員可以透過接收來自群組中 Anchor 成員的定位訊號完成定位。

我們在下節中將會針對此型式網路架構中 GPS 耗電問題提出完整的解決方案，以下是我們所設計之合作式定位機制的目標：

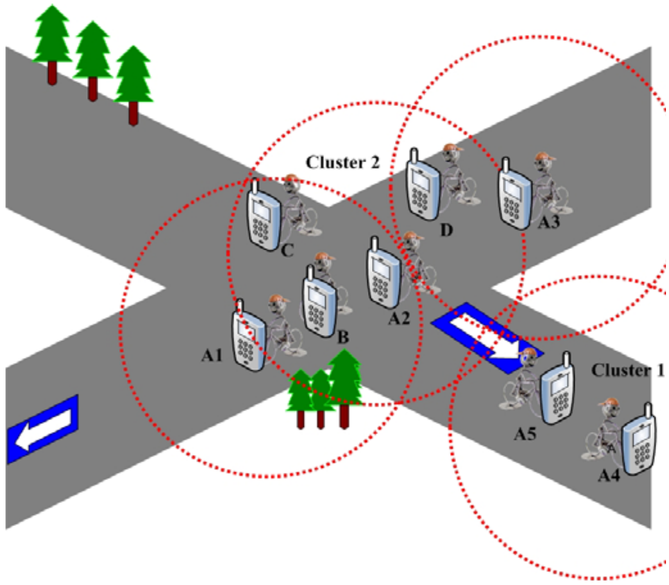
1. **Biker Clustering:** 將整個車隊網路成員進行動態分群，使得在相同群組內的成員可以藉由 Ad-hoc 方式進行通訊，以及當群組內的成員有變動時可以快速更新群組拓樸。
2. **Anchor Selection:** 在同一群組內選出少數 Anchor 成員來開啟 GPS 裝置以減少車隊中同時開啟 GPS 裝置的成員數量。
3. **Position Estimation:** Member 成員利用 Anchor 成員所廣播的定位訊號與移動軌跡來進行位置估算。

III. The Proposed Framework

A. 群組形成方法

如圖三所示，假設在道路上有一車隊沿相同方向前進，且每輛車上皆有手機可以進行無線通訊形成網路。我們將此車隊網路成員進行分群，在一個群組中的成員可能擔任 Anchor 或 Member 其中之一的角色。在此車隊網路分群的過程中可能會發生下列三種不同的狀況：

1. 新建立群組：例如車隊成員們在初始啟動車隊通訊裝置時會等待一段時間區間 t_{init} ，若在 t_{init} 時間沒有收到來自 Anchor 所發出的 Location



圖三、群組形成

Beacon 則此成員會自己形成一個群組，並且自己擔任 Anchor 的工作並發送 Location Beacon。

2. 新成員加入群組：如果新成員啟動車隊通訊裝置後有收到 Location Beacon，則此新成員首先判斷自己的行進方向是否與 Location Beacon 相同。若方向不同則忽略，方向相同才會採用為有效 Location Beacon。我們將此新成員收到有效 Location Beacon 的情形分為以下兩種：

Case 1:若此新成員持續等待至 t_{init} 時間後，只收到一個有效 Location Beacon 則會加入目前的群組，並開啟 GPS 接收器廣播 Location Beacon，成為 Anchor。

Case 2: 若此新成員收到二個以上的有效 Location Beacon。則會根據收到 Beacon 的時間順序直接加入已存在的群組，並停止等待 t_{init} ，再判斷加入時的位置決定是否開啟 GPS 接收器，其加入位置判斷方法詳如本節 C 部分所述。

當 Anchor 開啟 GPS 接收器，在每次廣播 Location Beacon 後，在同一群組內的每位成員接到 Location Beacon 都會啟動倒數計時，越先倒數完畢的成員，越先廣播 Location Beacon 擔任 Anchor 的工作。如圖三所示，車隊經分群後分為

二個群組，Cluster 1 與 Cluster 2。其中 Cluster 1 為 One-Hop 群組，其 Anchor 分別為 A4 與 A5，Cluster 2 為 Multi-Hop 群組，其 Anchor 分別為 A1、A2 與 A3。

3. 成員離開群組：如果在群組之間有 Anchor 或 Member 位置變動(例如突然加速離開或停止)導致車隊成員脫隊離開原本的群組，此時需重新在變動後的群組中找出成員擔任 Anchor 節點。如圖三所示，A2 突然要轉向脫離車隊，此時 A2 附近的 Member 成員 B、C 與 D 會變成突然只能收到一個 Location Beacon。成員 B、C 與 D 再等待 t_{init} 時間，依照收到的有效 Location Beacon 數決定是否啟動 Backoff Timer。若決定啟動則再根據收到的 Location Beacon 訊號強度換算出的距離 D_i 計算出 Backoff Time，此時 Backoff Time 的越小的成員越先開啟 GPS 接收器並廣播 Location Beacon，成為新的 Anchor。

另一方面，若脫隊成員加入另一群組，例如 Anchor A2 離開 Cluster 2，並加速前進到 Cluster 1 所在之範圍，則會依照新成員加入群組的方式重新形成群組，若是 Member 脫離車隊則不影響原群組。

4. 成員在同一群組內的位置變動：如果在群組之內有 Anchor 或 Member 位置變動(例如突然加速或減速)導致車隊成員離開原本的位置，此時需重新在變動後的群組中找出成員擔任 Anchor 節點。例如 A2 往前移動，靠近 A1 但 B 與 C 卻仍可收到 A2 的 Location Beacon，此時造成 A2 附近的成員 D 收不到 A2 的 Location Beacon，因此 A2 附近的成員再等待 t_{init} 時間，依照收到的有效 Location Beacon 數決定是否啟動 Backoff Timer。若決定啟動後再根據收到的 Location Beacon 訊號強度換算出的距離 D_i 計算出 Backoff Time，此時 Backoff Time 越小的成員越先開啟 GPS 接收器並廣播 Location Beacon，成為新的 Anchor。

B. 定位錨點選擇方法

最前方的成員 A1 開啟 GPS 接收裝置，使用 GPS 定位並擔任 Anchor 的工作，此時其後方的車隊成員會根據群組形成方法判斷應該擔任 Member 或是 Anchor 的工作，此判斷機制則是使用 Backoff Timer 來決定在其他車隊成員中誰會是下一個 Anchor。根據這些成員與 A1 的距離 D_i 計算出 Backoff Timer 以設定廣播 Location Beacon 的時間。第一個廣播 Location Beacon 的 Member 即成為下一個 Anchor，其他 Member 在接收到第一個重廣播的 Location Beacon 時，即重設 Backoff Timer 並停止倒數。以圖三為例，因為 A2 是處於 A1 One-Hop Boundary 的 Member，所以 A2 具有較短的 Backoff Timer，故會比較優先廣播自己的位置資訊成為 Anchor。

Anchor 成員的選擇除了會在車隊成員位置有變動時透過前述分群方法選出之外，當某一個 Anchor 節點經過一段時間的定位後，因電力消耗使得電池剩餘電量下降，電池電壓快要降至工作電壓值門檻值時，可關閉 GPS 接收器變成 Member，此時發送 Location Beacon 的工作將會轉交給其他成員。

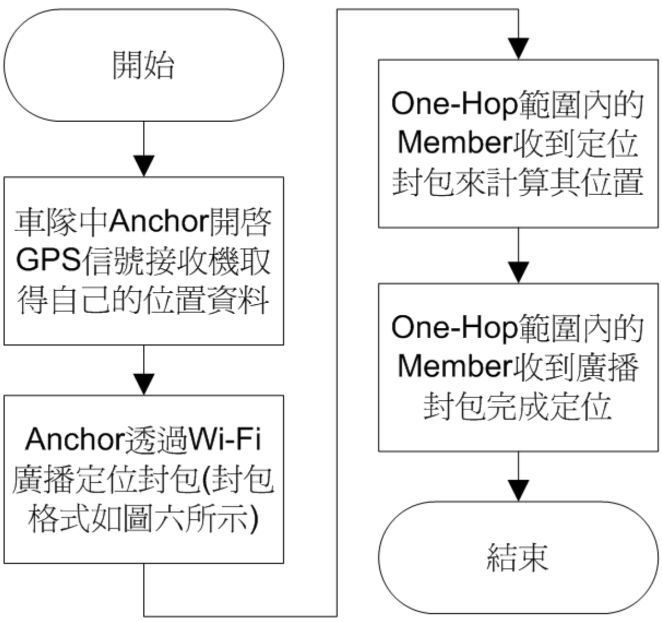
如圖三所示，若擔任 Anchor 的成員 A2 因電力消耗使得電池剩餘電量下降而關閉 GPS 接收器，此時發送 Location Beacon 的工作將透過 Location Backoff 的方法選出其他成員接任。Anchor 接任的方式為 A2 附近的成員 i 等待 t_{init} 時間後，若沒有接收到 A2 所發出的 Location Beacon，則會啟動 Backoff Timer 根據最近一次收到的 Location Beacon 訊號強度所換算出的距離 D_i 計算出 Backoff Timer，Backoff Timer 越短的成員越先開啟 GPS 接收器廣播 Location Beacon，成為新的 Anchor，取代原本的 Anchor 在其 Broadcast Radius 所涵蓋的虛線區域向成員廣播 Location Beacon。原本的 Anchor A2 就成為 Member 並停止廣播 Location Beacon。其中 Backoff Timer (BT)的計算公式如式 1 所示[17]：

$$BT = \begin{cases} [0, 2^{\tau+1}-1] & \frac{\rho-1}{\rho}R < D_i \le R \\ [2^{\tau+1}, 2^{\tau+2}-1] & \frac{\rho-2}{\rho}R < D_i \le \frac{\rho-1}{\rho}R \\ \cdots\cdots\cdots & \cdots\cdots\cdots \\ [2^{\tau+\rho-1}, 2^{\tau+\rho}-1] & 0 < D_i \le \frac{1}{\rho}R \end{cases} \qquad (1)$$

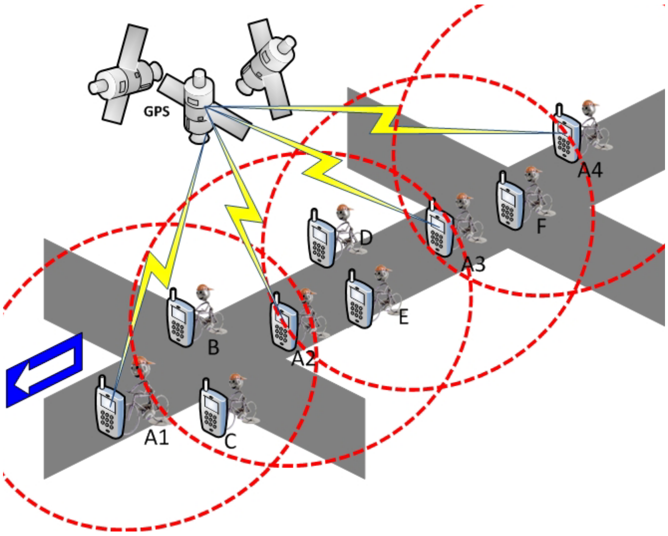
其中 R 為廣播訊號的可接收範圍(Broadcast Radius)，τ 為一個小整數，ρ 為一個整數代表 Backoff Class 的數目，若 ρ 越大則可區分出的 Backoff Timer 層級越多，反之則越少。Broadcast Radius 內先取得重廣播 Location Beacon 優先權的成員即成為下一個 Anchor，開啟 GPS 接收器並負責在下一個 Broadcast Radius 所涵蓋的區域向成員廣播 Location Beacon。

而如果車隊最前方的成員 A1 電量不足以擔任 Anchor，仍可選出 A1 後方成員 B 擔任新 Anchor，此時可用 B 所記錄之軌跡來推估未來經過的路徑以及目前與 B 的距離來進行定位。

C. 位置估算方法



圖四、合作式車隊定位流程



圖五、群組定位

我們假設在同一車隊中的 Anchor 與 Member 成員行進方向皆相同，且已知其 Wi-Fi 天線功率與傳輸頻率，另外 Anchor 與 Member 之間的距離為 Wi-Fi One-Hop 訊號可達範圍，而且我們設定無線通道模型為自由空間傳播模型(Free Space Propagation Model)來進行在 Ad Hoc 通訊範圍下的成員定位，圖四為本文所探討之合作式車隊定位機制之定位流程圖。首先車隊中的 Anchor 成員開啟 GPS 接收裝置，讀取自己的位置資料，並且持續地記錄下來。Anchor 再透過 Wi-Fi Ad Hoc 網路介面將所蒐集與記錄的位置資訊放入 Location Beacon 並廣播給 Member 成員，Member 成員接收到定位封包後，根據封包內的位置資訊計算出自己的位置。

圖五為一個車隊定位的例子，此群組有四個 Anchor 成員分別為 A1、A2、A3 與 A4，以及五個 Member 成員分別為 B、C、D、E 與 F。最前方的成員 A1 開啟 GPS 接收裝置，使用 GPS 定位並擔任 Anchor 成員的工作，此時其後的車隊成員成為 Member，但最後方的成員 A4 則經由群組形成方法成為 Anchor。Anchor 必須在一定的信號時間間隔(Interbeacon Space, IBS)後，向群組中的 Member 廣播 Location Beacon。其中 Location Beacon 封包格式定義如圖六所示：

ID	Team Direction	Current IBS	Track
(Integer)	([X, Y] vector)	(Integer)	([X,Y] list)

圖六、Location Beacon 封包格式

在定位信號封包中，Identify Number (ID) 為每個成員在網路中的識別號碼，每個成員具有一個唯一的 ID，此 ID 在本文中以手機裝置之 IMEI Number 作為 ID；Team Direction 欄位放置此車隊行進方向的向量 V；Current IBS 欄位為發送 Location Beacon 所使用的 IBS 時間間隔；Track 欄位為 Anchor 進入某路段的 GPS 位置到 Beacon 發送前的 IBS 時間位置所記錄下來的 GPS 軌跡資訊，此軌跡資訊為由經緯度座標值所形成的座標資料陣列。

如圖五所示，A1 所在的虛線圓圈內，當車隊的其中一個的成員 Member i (i 可能為 B 或 C) 接收到前後兩個 Anchor A1 與 A2 所發送的 Location Beacon LB_1 與 LB_2 後，根據 Location Beacon 的訊號強度、行進方向向量、軌跡資訊 (Track) 與福利斯自由空間方程式 (Friis Free Space Equation) [18] (見式 2)，我們可以得到當接收訊號的功率為 $PG_{db}(d_i)$、無線訊號的傳送頻率為 f MHz 時，與 Anchor 所隔的距離為 d_i。再使用 RSS 演算法配合軌跡資訊(見式 3 與式 4)計算出自己的位置 (X_i,Y_i)。假設 $P_1 = \{(X_1,Y_1),(X_2,Y_2),....,(X_n,Y_n)\}$ 為 LB_1 所攜帶的軌跡資訊中所有軌跡點的 X 軸與 Y 軸座標位置形成的集合，P_1 集合最少含有兩個點且最多含有在 Wi-Fi 通訊範圍 R 內所收集到的軌跡點，(X_1,Y_1) 永遠表示 A1 目前的最新位置，而 (X_n,Y_n) 表示最舊的位置。Member i 與前後兩個 Anchor 的相對位置關係如圖七所示，可由歐幾里得距離計算出未知的位置 (X_i,Y_i)。假設兩個 Anchor 之間相距 S，Member 位置的判斷方法為：

(a) 若 $d_1 \le S$ 且 $d_2 \le S$，則代表 Member 在兩個 Anchor 之間，可先使用 Location Beacon 的訊號強度求出與 A1 的距離 d_1，以 d_1 為半徑畫圓，再由 A1 所經過的軌跡 P_1 中選出相鄰的 2 個點形成的軌跡線段找出與此圓的交點(見式 2、3 與 4)即最後計算出的 Member 的位置。

(b) 若 $d_2 \ge S$ 且 $d_2 \ge d_1$，則代表 Member 在兩個 Anchor 之前，此時 Member 會開啟 GPS 成為 Anchor 並廣播 Location Beacon，而 A1 與 A2 在接收到此 Location Beacon 後，由於 A2 距離較遠，因此根據 Backoff Timer 先倒數完畢而廣播 Location Beacon。A1 則因收到 2 個 Location Beacon 而關閉 GPS 成為 Member，並可利用(a)所述方法完成定位。

(c) 若 $d_1 \ge S$ 且 $d_1 \ge d_2$，則代表 Member 在兩個 Anchor 之後，此時 Member 會開啟 GPS 成為 Anchor 並廣播 Location Beacon，而 A1 與 A2 在接收到 Location Beacon 後，因 A1 距離較遠因此根據 Backoff Timer 先倒數完畢而廣播 Location Beacon。A2 則因收到 2 個 Location Beacon 而關閉 GPS 成為 Member，並可利用(a)所述方法完成定位。

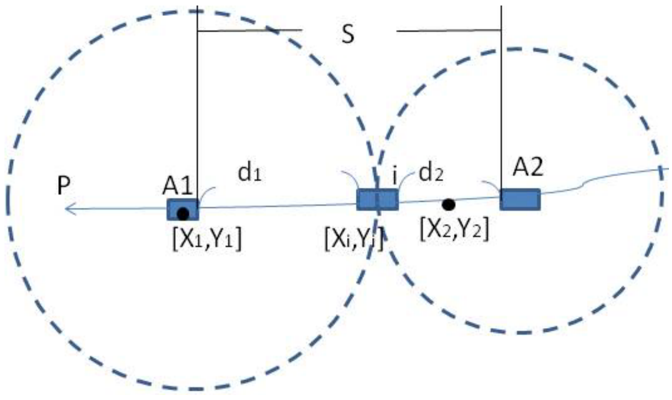
$$PG_{db}(d_i) = 34.22 + 20\log_{10} d_i + 20\log_{10} f \quad \text{.......(2)}$$

$$d_i = \sqrt{(X_i - X_1)^2 + (Y_i - Y_1)^2} \quad \text{.......................(3)}$$

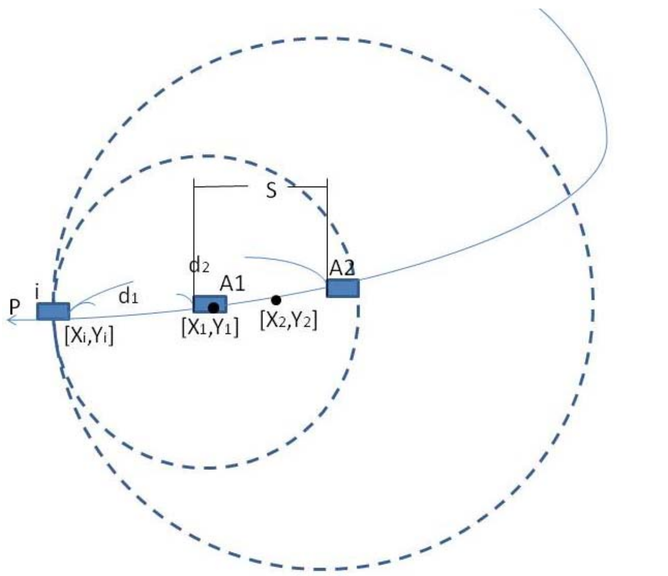
$$\frac{(X_i - X_j)}{(Y_i - Y_j)} = \frac{(X_j - X_{j+1})}{(Y_j - Y_{j+1})}, j = 1 \sim n\text{-}1 \quad \text{...............(4)}$$

其中式 3 與 4 解聯立方程式所求出之 X_i 介於 X_j 與 X_{j+1} 之間且 Y_i 介於 Y_j 與 Y_{j+1} 之間。

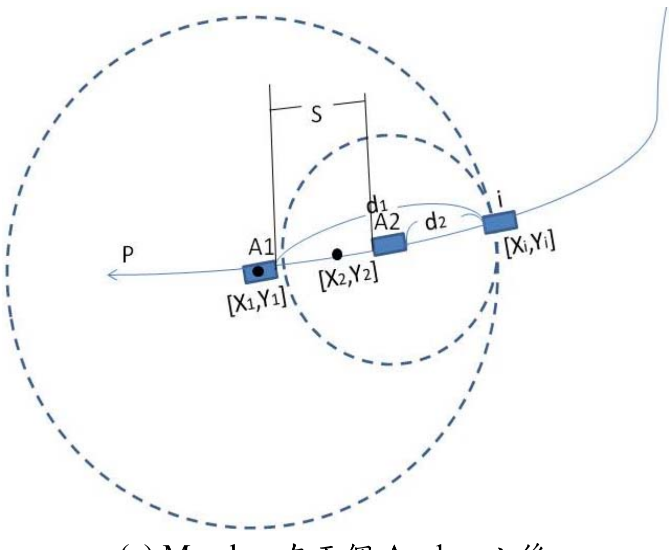
以圖五為例，考慮所有的虛線圓圈範圍，虛線圓圈表示由圓圈中心節點所發出的 Wi-Fi 無線訊號傳輸的可接收範圍，其半徑為 R。在 Multi-Hop 車隊群組的狀況下，其成員的定位可視為許多個 One-Hop 組合同時定位。



(a)Member 在兩個 Anchor 之間



(b) Member 在兩個 Anchor 之前



(c) Member 在兩個 Anchor 之後

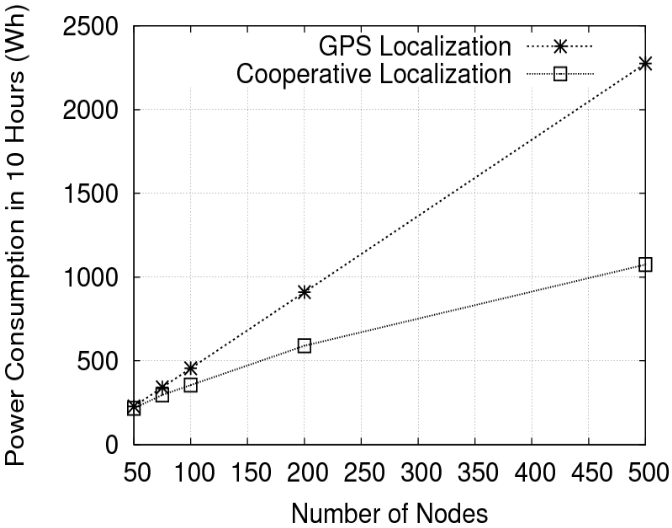
圖七、位置判斷與計算

IV. Performance Evaluation

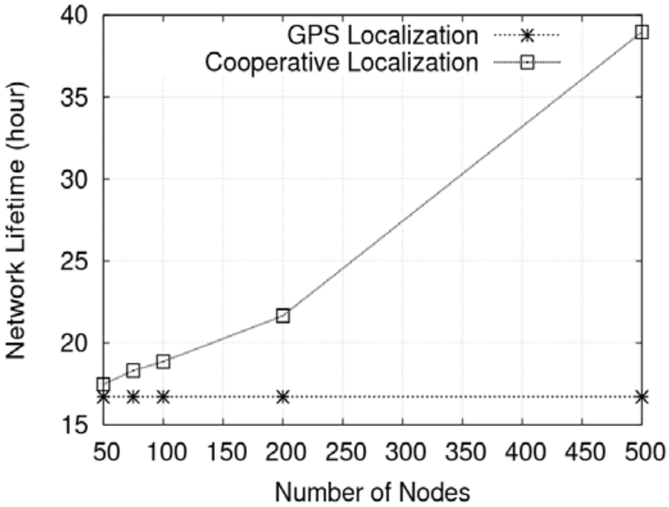
在本節中，我們使用 Java 模擬器建立虛擬車隊網路，模擬同一個車隊的 LBS 應用服務分別採用傳統 GPS 定位與本文所設計的合作式定位機制(CLF)所消耗的電池電能以及整體網路工作時間的比較。在模擬實驗中，手機參數參考 HTC 的 Android 手機 Sensation 產品規格，其鋰電池容量為 1520 mAh [19]。大部分智慧型手機內建 GPS 模組在使用內建天線並且於 Enable State 時其耗電功率為 400mW 以及 Wi-Fi 模組耗電功率約為 55 mW [20]，我們採用這些數據做為模擬實驗的參數。

在以下的模擬實驗中，自行車隊網路的成員總數目設定為 50、75、100、200 與 500，行進速度以每秒 5 公尺至 10 公尺的範圍隨機選取，每秒更新一次位置資訊與電池所餘電量資訊，每個數值為 1000 次模擬實驗的平均值。在每次模擬實驗中，當車隊網路中有任一個成員的電池電量下降，降到工作電量門檻值時即進行新 Anchor 的選取，當電池電量值降為零時，即判斷該成員電力耗盡，並記錄工作時間與所消耗總電能。

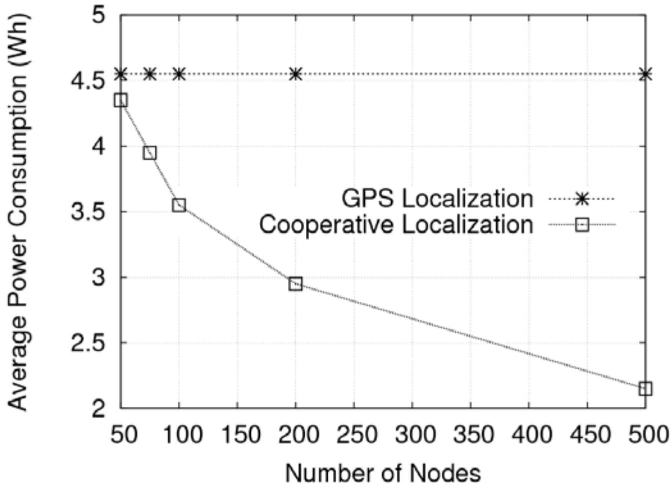
圖八顯示在不同車隊成員數目的情況下，各機制連續使用 10 小時所消耗的總電池電能。由圖八我們可以發現，由開始模擬到經過 10 小時為止，整體車隊網路所消耗的總電量一直呈現上升的趨勢。但是隨著成員數目的增加，其上升的趨勢漸緩。這是因為單一群組成員數變多，因此在同一群組中有更多成員可以關閉 GPS 接收器，改為藉由合作式定位機制輪流開啟 GPS 接收器取得位置資訊，節省開啟 GPS 接收器所需消耗的電量。圖九顯示統計至整個網路中全部成員電力耗盡為止的平均耗電量與車隊成員數關係。由圖九可以發現當車隊成員節點數目增加時，車隊成員的平均耗電量下降，這是因為更多車隊成員可分攤定位所需耗電量而使得電量平均消耗大幅減少。



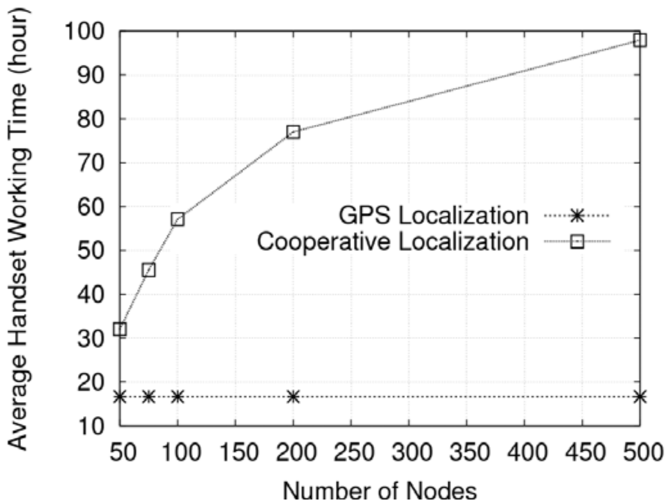
圖八、消耗總電能比較



圖十、網路存活時間比較



圖九、車隊平均消耗電能比較



圖十一、手持裝置平均工作時間比較

由圖十可以發現當車隊成員節點數目增加時，使用合作式定位機制讓整體網路的存活時間有增長的趨勢，但是當節點數介於 50 到 100 時，所延長的工昨時間並未十分明顯，這是因為當車隊成員數目太少時，群組成員有較大的機會自己成為一個群組，無法與其他成員進行合作式定位，因此省電的效能沒有明顯提升。圖十一顯示統計至整個網路中最後一個成員電力耗盡為止的平均手持裝置工作時間與車隊成員數關係。由圖十一可以發現當車隊成員節點數目增加時，可因車隊成員彼此合作輪流擔任 Anchor 定位而使其每位成員的平均工作時間上升。

V. Conclusion

在本論文中，我們提出了一個適用於長鏈狀車載隨意網路的合作式定位機制。針對此型式的網路架構我們先將車隊網路成員進行分群，在相同群組內可以藉由 Wi-Fi Ad Hoc 網路介面進行通訊，在同一群組內只需 Anchor 成員開啟 GPS 裝置，可減少車隊中同時開啟 GPS 裝置的數量。Member 成員只需利用 Anchor 成員所廣播的定位訊號進行位置估算，不需其他冗餘的同步信號。相較於使用傳統 GPS 的定位方法，本方法僅使

用一個定位錨點與其小部分移動軌跡即可進行二維平面的定位，可以節省電能消耗並有效延長整體網路的工作時間。

VI. Acknowledgement

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LEGS: A Load-balancing Emergency Guiding System Based on Wireless Sensor Networks

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***Abstract*—LEGS is a *Load-balancing Emergency Guiding System* using a wireless sensor network. In LEGS, we design a load-balancing guiding scheme and derive an analytical model in order to reduce the total evacuation time of people. The proposed guiding scheme can provide the fastest path to an exit based on the evacuation time estimated by the derived analytical model. To the best of our knowledge, LEGS is the first system which takes the corridor capacity and length, exit capacity, and people distribution into consideration for analyzing evacuation time and planning escape paths. Through LEGS, the congestion of certain corridors and exits can be released to significantly reduce the evacuation time of people. Analytical and simulation results show that LEGS outperforms existing works, which can prevent people from following the local optimal guiding direction with the longer evacuation time in total. LEGS thus demonstrates an efficient emergency guiding system for public safety.**

Keywords: Home Security, Navigation, Pervasive Computing, Wireless Communication, Wireless Sensor Network.

I. Introduction

The recent progress of wireless communications and embedded microelectromechanical systems (MEMS) technologies has made wireless sensor networks (WSNs) more attractive. Existing works have been made for vehicle security and tracking [1], emergency guiding and monitoring [2], and cooperative collision avoidance [3].

For emergency guiding purposes, reference [4] deploys a large number of active RFID tags in a building. People use personal digital assistants (PDAs) connected by RFID readers via Compact Flash interfaces for indoor localization and emergency guiding. However, reference [4] guides people to the nearest exit without taking people distribution into account. Thus, there may be serious congestion in the nearest exit due to uneven people distribution and unbalanced emergency guiding. In addition to a large number of active RFID tags, reference [5] deploys a few Bluetooth devices in a building for indoor positioning. Similarly, people distribution is not considered in [5] so that the total evacuation time may become longer due to the local optimal guiding, which is also occurred in [6].

In this work, we design a *Load-balancing Emergency Guiding System (LEGS)* in a 2D indoor environment using a wireless sensor network that aims to guide people to exits as soon as possible when emergencies happen. To the best of our knowledge, LEGS is the first system which takes the corridor capacity and length, exit capacity, and people distribution into consideration for analyzing evacuation time and planning escape paths. In LEGS, a load-balancing guiding scheme is designed to find the fastest path to an exit for people based on the evacuation time estimated by the derived analytical model. The congestion of certain corridors and exits can be released to significantly reduce the evacuation time of people. In particular, LEGS can prevent people from following the local optimal guiding direction with the longer evacuation time in total.

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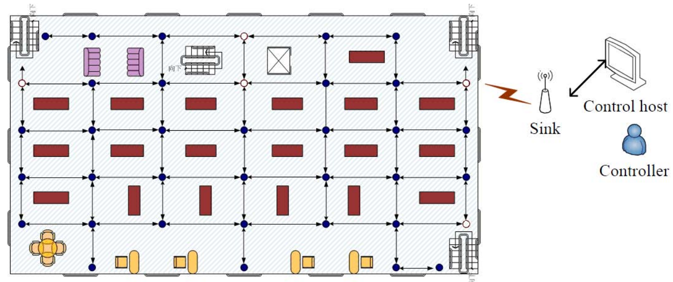

Fig. 1. System architecture of LEGS.

II. System Design

Fig. 1 shows the system architecture of LEGS. Sensor nodes (i.e., black and white circles) are deployed in a 2D indoor environment, which form a multi-hop ad hoc network. One node serves as the *sink* of the network, and it is connected to the *control host*, which issue commands and config the network. To support emergency guiding services, sensors are classified as *normal sensors* (i.e., black circles), *exit sensors* (i.e., white circles), and *boundary sensors* (i.e., nodes with one or more neighboring sensors belonging to different emergency guiding trees). Next, we will show how to find the fastest escape path leading to an exit as detecting an emergency event, whereas the detail for how to construct an initial guiding tree rooted by an exit and to prevent people from crossing hazardous region can be found in our previous work [2].

A. Load-Balancing Guiding

In our system, each sensor knows the capacity and length of each corridor, the capacity of each exit, and its own location in the 2D plane. In addition, the number of people around a sensor will be detected by RFID or image recognition technologies and periodically reported to the sink by each sensor. After the sink collects all numbers of people around sensors, it will broadcast the people distribution information to all sensors. As detecting an emergency event, all boundary sensors will execute the following steps:

Step 1: For each initial guiding tree T_{I} without hazardous region R_{H}, boundary sensors will calculate the evacuation time T_{exit} of T_{I} by the analytical model proposed in Section II-B. For each T_{I} with R_{H}, the sensors and corridors inside R_{H} will be removed first. Then, the sensors outside R_{H} losing their parent sensors inside R_{H} will be guided to an exit using the shortest path so that a new guiding tree T_{N} is formed. For calculating T_{exit} of T_{N}, there are two possibilities as follows:

(a) If there is an exit inside R_{H}, all people inside R_{H} will be guided to the exit inside R_{H} using the shortest path. T_{exit} of T_{N} can be estimated by the analytical model proposed in Section II-B.

(b) If there is no exit inside R_{H}, the sensor detecting the emergency event and its corridors will be removed and all other sensors inside R_{H} will be guided to the sensors outside R_{H} using the shortest path so that a new guiding tree T_{S} is formed. T_{exit} of T_{S} can be estimated by the analytical model proposed in Section II-B.

Step 2: The total evacuation time T_{total} is decided by the emergency guiding tree T_{MAX} with the longest T_{exit}. After T_{exit} of all emergency guiding trees are estimated by boundary sensors, boundary sensor i in T_{MAX} will reset its guiding direction to the neighboring guiding tree T_{MIN} with the shortest T_{exit} and recalculate T_{exit} of T_{MAX} and T_{MIN}. If T_{total} decreases, i will notify its neighboring sensors $b(i)$ in T_{MAX} that $b(i)$ become boundary sensors.

Assume that T_{MAX} has m boundary sensors between T_{MAX} and T_{MIN}, where boundary sensor n_j is sorted in decreasing order by the number of people in n_j, for $j = 1, 2, \ldots, m$. First, n_1 calculates T_{exit} of T_{MAX} and T_{MIN} after removing and adding n_1, respectively. If T_{total} decreases, n_1 will reset its guiding direction to T_{MIN} and notify its neighboring sensors $b(n_1)$ in T_{MAX} that $b(n_1)$ become boundary sensors. Second, n_2 calculates T_{exit} of T_{MAX} and T_{MIN} after removing and adding n_1 and n_2, respectively. If T_{total} decreases, n_2 will reset its guiding direction to T_{MIN} and notify its neighboring sensors $b(n_2)$ in T_{MAX} that $b(n_2)$ become boundary sensors. Similarly, n_m calculates T_{exit} of T_{MAX} and T_{MIN} after removing and adding $n_1, n_2, \ldots,$ and n_m, respectively. If T_{total} decreases, n_m will reset its guiding direction to T_{MIN} and notify its neighboring sensors $b(n_m)$ in T_{MAX} that $b(n_m)$ become boundary sensors. Finally, new boundary sensors $b(n_1), b(n_2), \ldots,$ and $b(n_m)$ will repeat Step 2 to determine whether they should reset their guiding directions to T_{MIN}.

Step 3: Assume that there are N emergency guiding trees in the 2D plane. As $N = 2$, the total load-balancing guiding can be finished by Step 2. As $N = 3$, the load-balancing guiding of Step 2 will be first done between the emergency guiding tree T_1 with the longest T_{exit} and its neighboring guiding tree T_2 with the shortest T_{exit}. Then, the total load-balancing guiding can be finished by Step 2 between $T_1 + T_2$ and the third emergency guiding tree T_3. As $N = 4$, the load-balancing guiding of Step 2 will be first done between the emergency guiding tree T_1 with the longest T_{exit} and its neighboring guiding tree T_2 with the shortest T_{exit}. At the same time, the load-balancing guiding of Step 2 will be done between the remaining guiding trees T_3 and T_4. Then, the total load-balancing guiding can be finished by Step 2 between $T_1 + T_2$ and $T_3 + T_4$. Similarly, as $N \geq 5$, Step 2 and 3 can be repeated to finish the total load-balancing guiding.

B. Evacuation Time Analysis

Given an emergency guiding tree T_{G} rooted by an exit sensor, we derive its total evacuation time considering the corridor capacity and length, exit capacity, and people distribution. Assume that there are n sensors in T_{G} and sensor 1 is the root. sensor 2, sensor 3, ..., and sensor n are sorted in increasing order by their hop counts to sensor 1. Below, we first introduce some notations for sensor i, its parent sensor $p(i)$, and its child sensors $c(i)$ in T_{G}, for $i = 1, 2, \ldots, n$:

- T_i: the time to evacuate from i for the last person.
- D_i: the time to move from i to $p(i)$.
- N_i: the number of people in i as emergences happen.
- C_i: the corridor capacity from i to $p(i)$.
- $T^j_{c(i)}$: the time to evacuate from i's child j for the last person.
- $D^j_{c(i)}$: the time to move from i's child j to i.
- $N^j_{c(i)}$: the number of people in i's child j as emergences happen.
- $C^j_{c(i)}$: the corridor capacity from i's child j to i.

Assume that there are m child sensors in $c(i)$. We calculate the evacuation time T_i of the subtree $T_{\mathrm{G}(i)}$ rooted by i for the last person. According to whether there is congestion occurring in i as the last person in $T_{\mathrm{G}(i)}$ evacuates from i, the estimation of T_i can be classified as follows:

Case 1: There is no congestion occurring in i as the last person in $T_{\mathrm{G}(i)}$ evacuates from i. The evacuation time T_i is the sum of the time to evacuate from $c(i)$ for the last person and the time to move from i to $p(i)$. So

$$T_i = \max_{j \in c(i)}(T^j_{c(i)}) + D_i.$$

Case 2: There is certain congestion occurring in i as the last person in $T_{\mathrm{G}(i)}$ evacuates from i. First, all sensors j in $c(i)$ are sorted in increasing order by $D^j_{c(i)}$, for $j = 1, 2, \ldots, m$, such that $D^1_{c(i)} \leq D^2_{c(i)} \leq \cdots \leq D^m_{c(i)}$. Second, we find the smallest k such that $C^1_{c(i)} + C^2_{c(i)} + \cdots + C^k_{c(i)} > C_i$. If there is no such k existed, it represents that the corridor capacity between i and $p(i)$ is large enough to be passed concurrently by the people from $c(i)$. In other words, there will be no congestion occurring in i and T_i can be estimated by Case 1. Otherwise, there are two possibilities as follows:

(a) If $D^k_{c(i)} < \frac{N_i}{C_i}$, it implies that there is a high probability of congestion occurring in i as the people evacuates from $c(i)$ to i. T_i is modeled by summing the time to evacuate from i for all people in $T_{\mathrm{G}(i)}$ and the time to move from i to $p(i)$ as follow

$$T_i = \frac{\sum_{j=1}^{m} N^j_{c(i)} + N_i}{C_i} + D_i.$$

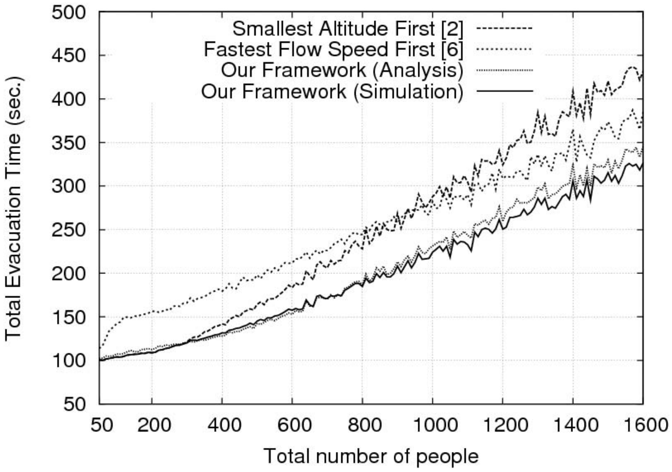

Fig. 2. Comparisons of evacuation time under different numbers of people.

(b) If $D^k_{c(i)} \geq \frac{N_i}{C_i}$, it implies that some people in sensor $1, 2, \ldots,$ and $k-1$ have evacuated from i as the people in k arrive at i. T_i is modeled by summing the time to move from k to i, the time to evacuate from i for the remaining people in $T_{\mathrm{G}(i)}$, and the time to move from i to $p(i)$ as follow

$$T_i = D^k_{c(i)} + T_{c(i)} + D_i,$$

where

$$T_{c(i)} = \frac{\sum_{j=1}^{m} N^j_{c(i)} - \sum_{j=1}^{k} C^j_{c(i)} \times (D^k_{c(i)} - D^j_{c(i)})}{C_i}.$$

In the analytical model, we adopt the maximum time estimated by Case 1 and Case 2 as T_i since T_i is the time to evacuate from i for the last person in $T_{\mathrm{G}(i)}$, for $i = 1, 2, \ldots, n$. Thus, the total evacuation time of T_{G} is equal to T_1 that can be obtained by calculating $T_n, T_{n-1}, \ldots,$ and T_1 in order, where $D_1 = 0$ and C_1 is the exit capacity.

Fig. 2 shows comparisons of total evacuation time under 50, 60, ..., 1590, and 1600 people. We deploy 6×6 sensor nodes in a 2D grid plane. There are two exit sensors located on the bottom left and bottom right corners, and the remaining sensors are normal sensors. The corridor and exit capacities are randomly selected from 2 to 6 people/second, and the moving time for each corridor is randomly chosen from 10 to 15 seconds. We first randomly assign 50% people to all sensors and then randomly select 9 hot-spot sensors for assigning the rest 50% people to them. We compare our scheme against the Smallest Altitude First (SAF) method [2] that guides people to the neighboring sensor with the smallest hop count to an exit and the Fastest Flow Speed First (FFSF) method [6] that guides people to the neighboring sensor with the fastest moving speed.

From Fig. 2, we can observe that both SAF and FFSF suffer from the local optimal selection problem, which SAF may select the escape path with the shortest distance to a exit but longer evacuation time, and FFSF may select the escape path with the faster moving speed currently but slower later. In particular, while SAF has the longer evacuation time than FFSF under more than 800 people, FFSF has the longer one than SAF under less than 800 people. Fig. 2 also contains comparisons of simulation and analytical results. Each simulation is repeated 1000 times and we take the average value. As can be seen, the simulated and analytical results are quite close, which justifies the correctness of our derivation.

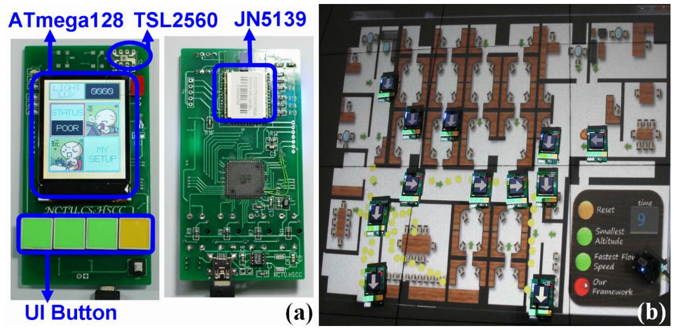

Fig. 3. Hardware components and the prototype of LEGS.

III. Prototype Implementation

In our prototype, the sensor is equipped with a TFT LCD panel controlled by ATmega128 [7], a light sensor TSL2560 [8], and UI buttons as input devices. The front side and back side of the sensor are shown in Fig. 3(a). The SAF method [2], the FFSF method [6], and our approach are implemented in Jennic JN5139 [9], which 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 building.

For the demonstration of indoor people evacuation, we use a projector to simulate that people escape from an office as emergences happen, as shown in Fig. 3(b). The evacuation simulator is developed by Processing [10] to create images, animations, and interactions. The light sensor can be highlighted by a laser pen to trigger an emergency event and three emergency guiding methods can be selected for evacuating people to exits. The animation of people evacuation is shown in the projected screen and the evacuation time is counted until all people escape from the office. From the screen, we can compare the evacuation time and guiding directions of SAF, FFSF, and our approach under different people distribution.

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[7] TFT LCD microcontroller, ATmega128. http://www.atmel.com.
[8] Light sensor, TSL2560. http://www.taosinc.com/.
[9] Jennic, JN5139. http://www.jennic.com/.
[10] Processing. http://www.processing.org/.

<table>
<tr><td colspan="4">出國報告書

撰寫時間： 2012 年 09 月 10 日</td></tr>
<tr><td>姓　　名</td><td>曾煜棋</td><td>單　　位</td><td>資工系</td></tr>
<tr><td>連絡電話</td><td>03-5131366</td><td>出生年月日</td><td>52 年 4 月 5 日</td></tr>
<tr><td>職　　別</td><td colspan="3">教授</td></tr>
<tr><td>出席國際會議名稱</td><td colspan="3">The 9th IEEE VTS Asia Pacific Wireless Communications Symposium</td></tr>
<tr><td>到達國家及 地 點</td><td colspan="3">京都/日本</td></tr>
<tr><td>出國期間</td><td colspan="3">自 2012 年 08 月 22 日 至 2012 年 08 月 25 日</td></tr>
</table>

一、 參加經過

本次出國參與的會議為The 9th IEEE VTS Asia Pacific Wireless Communications Symposium，是由The IEEE Vehicular Technology Society (VTS)主辦，舉辦地點在日本京都，參加經過分別說明如下:

- 8/22：報到，並參與APWCS BoG meeting討論今年舉辦的重要事宜，與明年舉辦的重要時辰。本人擔任APWCS的Board of governors 已有數年，今日的BoG會議討論了2012投稿之現況，2013在漢城舉辦之時程，以及2014年在台灣舉辦之相關安排

- 8/23-24：Asia Pacific Wireless Communications Symposium (APWCS) 大會, 地點在京都大學, 會議提供了各國學者交換學術研究之平台。
- 8/24：本次會中我們發表了以下的文章，會後並與其他研究人員討論這個題材之未來發展。
- 本人在8/24的上午11:10上台發表論文” **An Implementation Experience of Using WSN on Cold Chain Logistics”**，針對這次發表，與會學者給予相關意見如，於無線感測網路資料收集回sink端要回報給後端伺服器時，可考量於感測網路應用data fusion機制用以減少sink端之行動網路費用。

Time	International Conference Hall I	International Conference Hall II	International Conference Hall III	Conference Room III	Conference Room IV
Wednesday, August 22					
16:00	Registration (16:00 - 18:00) at Conference Room II				
18:00	Welcome Reception at International Conference Hall III (18:00-20:00)				
Thursday, August 23					
09:10	Registration (9:10 - 17:30) at Conference Room II				
09:30	*Keynote Speech* at International Conference Hall II, III (9:30 - 10:10)				
10:10	*Invited Talk 1* at International Conference Hall II, III (10:10 - 10:50)				
10:50	Coffee Break (10:50 - 11:10)				
11:10 -12:50	S1: Special Session "Green Communications"	S2: Special Session "The Cognitive Radio and TV White Space"	S3: Special Session "Interference Harmonization for New Generation Wireless Broadband System"	S4: Special Session "Compressed Sensing for Communication Systems"	Exhibition/ Demonstration Session
12:50	Lunch Break (12:50 - 13:50)				
13:50 -15:30	A1: Mobile Radio Systems I	A2: Resource Management I	A3: Cognitive Radio Networks	A4: Modulation & Coding	Exhibition/ Demonstration Session
15:30	Coffee Break (15:30 - 15:50)				
15:50 -17:30	B1: Space Time Processing for MIMO Systems I	B2: Sensor Network I	B3: Signal Processing for Communications	B4: Mobile Networks & Services	Exhibition/ Demonstration Session
18:00	Buffet at Room 321, 3F, Building No. 59 (Faculty of Engineering Bldg. No.8) (18:00-20:00)				
Friday, August 24					
09:10	Registration (9:10 - 14:00) at Conference Room II				
09:30	*Invited Talk 2* at International Conference Hall II, III (9:30 - 10:10)				
10:10	*Invited Talk 3* at International Conference Hall II, III (10:10 - 10:50)				
10:50	Coffee Break (10:50 - 11:10)				
11:10 -12:50	C1: Mobile Radio Systems II	C2: Space Time Processing for MIMO II	C3: Sensor Network II		Exhibition/ Demonstration Session
12:50	Lunch Break (12:50 - 13:50)				
13:50 -15:30	D1: Mobile Radio Systems III	D2: Resource Management II	D3: Higher Layer Protocols		Exhibition/ Demonstration Session
15:30	Coffee Break (15:30 - 15:50)				
15:50 -17:30	E1: Antenna & Propagation	E2: Resource Management III	E3: Ad-Hoc Network		

- 大會議程如下:

二、 心得:

此次會議主軸為無線通訊方面之議題，於議程中聽取各國學者發表其研究成果，可以進一步瞭解目前國際上頂尖之研究題材。本人在會場上也與會人士交流，並獲得更多新的研究資訊。

本次會議安排的一位Keynote Speaker與三位Invited Speaker分別如下:

- Dr. Yasuo Hirata, President, Advanced Telecommunications Research Institute International (ATR), Japan
- Dr. Sumei SUN, Head of Modulation & Coding Department, Institute for Infocomm Research (I2R), Singapore
- Dr. Byonghyo Shim, Associate Professor, School of Information and Communication, Korea University, Korea
- Dr. Guu-Chang Yang, Professor, Department of Electrical Engineering & Graduate Institute of Communication Engineering, National Chung Hsing University, Taiwan

這幾位學者在演講中都提出了深入的研究內容，對於啟發會議聽眾有很大的幫助。

三、 攜回資料名稱及內容

1. 大會手冊
2. 光碟片（論文）

四、 其他

無。

國科會補助計畫衍生研發成果推廣資料表

日期:2012/10/28

國科會補助計畫	計畫名稱: 子計畫三：車載網路之位置感知服務：設計一個結合汽車及自行車行動導覽遊憩之系統(3/3)
	計畫主持人: 曾煜棋
	計畫編號: 100-2219-E-009-002- 學門領域: 通訊軟體及平台(網通國家型)

無研發成果推廣資料

100 年度專題研究計畫研究成果彙整表

<table>
<tr><td colspan="3">計畫主持人：曾煜棋</td><td colspan="5">計畫編號：100-2219-E-009-002-</td></tr>
<tr><td colspan="8">計畫名稱：以安全、節能及遊憩為目的之車載網路系統--子計畫三：車載網路之位置感知服務：設計一個結合汽車及自行車行動導覽遊憩之系統(3/3)</td></tr>
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<tr><td>專任助理</td><td>0</td><td>0</td><td>100%</td><td></td></tr>
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其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	多項競賽獲獎：(條列如下) 1. 行動裝置組「評審特別獎」, ’樂活。咖打掐！’, 2011 年「第 8 屆育秀盃樂活飆新創意設計大賽」. 2. 行動裝置組「佳作」, ’樂活。咖打掐！’, 2011 年「第 8 屆育秀盃樂活飆新創意設計大賽」. 3. 兩岸三地總決賽「銅獎」, ’GoBike 樂活車隊社群系統’, 2011 年「安利盃大學生計算機作品賽」. 4. 競賽獎項, 概念組「優等獎」, ’FileYou’, 2011 年「Mobileheroes 通訊大賽 Android 使用者介面設計競賽」. 5. 全球創新實作組「傑出表現獎」, 2011 年「European Satellite Navigation Competition 伽利略創新大賽」. 6. 競賽獎項, Audience Award「第二名」, 2011 年「European Satellite Navigation Competition 伽利略創新大賽」. 7. 公共服務創新應用組「優選」, ’車道定位系統與方法’, 2011 年「第 16 屆全國大專校院/社會人士資訊服務創新競賽」. 8. 青年論文獎「第三名」, ’雙層式長鍊狀車載網路之高效率資料收集與散佈機制’, 中國電機工程學會, 2011.

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

　　□實驗失敗

　　□因故實驗中斷

　　□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：■已發表 □未發表之文稿 □撰寫中 □無

專利：□已獲得 ■申請中 □無

技轉：□已技轉 ■洽談中 □無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

在第一年的計畫成果中，我們已開發了新型車載監視與感測系統，並以其為基礎發展了車載安全應用、車載防盜應用、以及車輛追蹤應用。在第二年度的計畫執行中，我們藉由車間通訊技術設計出一個無需搭配基礎建設的車載網路追蹤機制，其中包含追蹤換手(Tracking Handoff Scheme)、路口偵測(Intersection Detection Scheme)、決定重廣播設計(Rebroadcast Decision Scheme)、路口導引搜尋設計(Intersection-Guiding Search Scheme)和記憶式 backoff 設計(Memory-Based Backoff Scheme)。在這些機制的運作下，可以充分地減少網路上控制封包的負荷量和不必要的重廣播封包量。在第三年的計畫裡，我們把二氧化碳的硬體裝置實做出來，並且利用車輛的移動性和隨機性來蒐集二氧化碳濃度。先針對小區域的環境來回報，進而推估整個大區域的濃度。我們並且針對 VSN 提出了一個新的網路架構來做傳輸。為了考慮網路的傳輸量和車輛的移動性，我們也提出了新的數學式子來做效能評比和做改善。最後，透過模擬來驗證我們的演算法。三年來, 我們得到以下的成果:14 篇論文發表與 2 件學術獲獎,未來我們將朝向實務系統和標準開發規劃。