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.

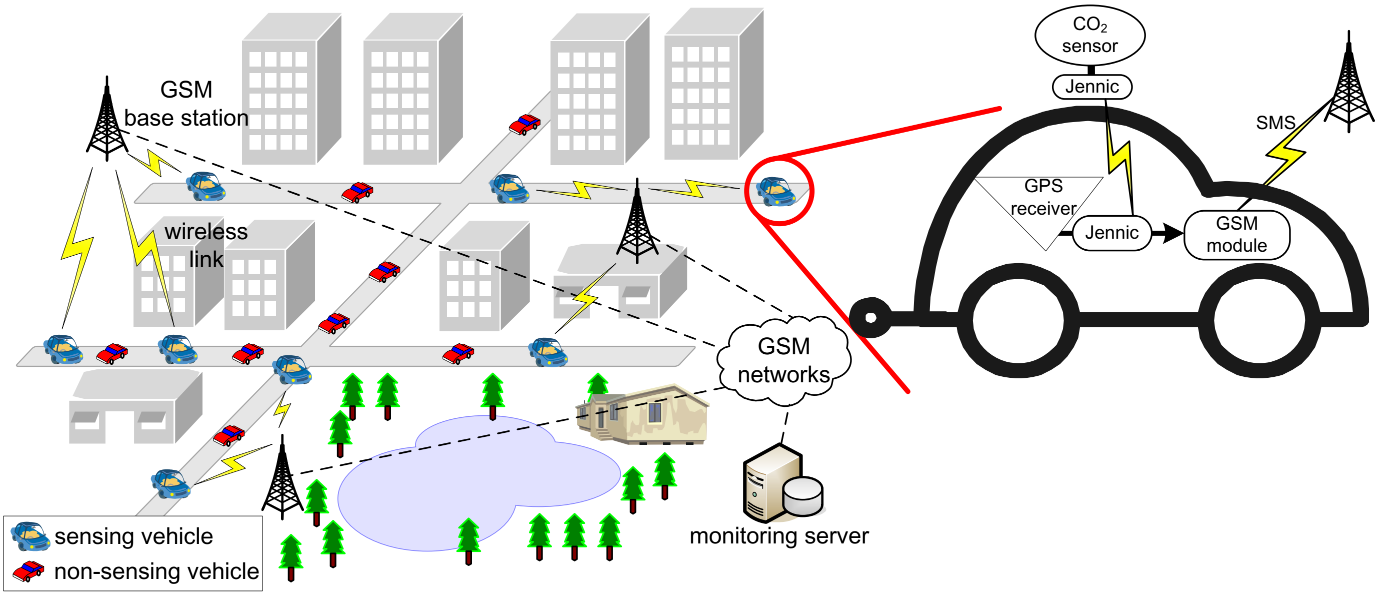

Fig. 1. The proposed VSN architecture for micro-climate monitoring.

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).

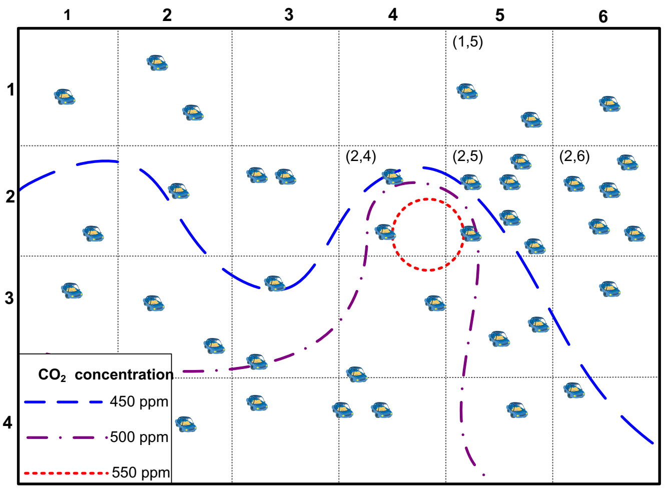

Fig. 2. An example of grid architecture and reporting rate adjustment.

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:

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

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

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

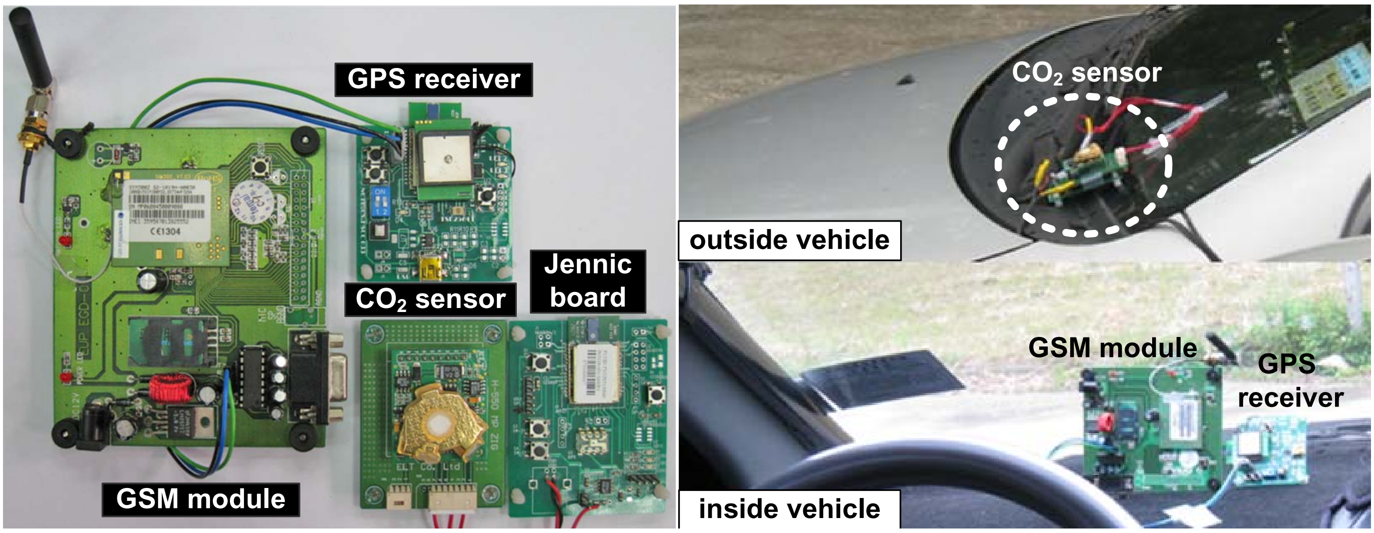

Fig. 3. The snapshots of hardware components.

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 $\leq$ 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 $\pm$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.

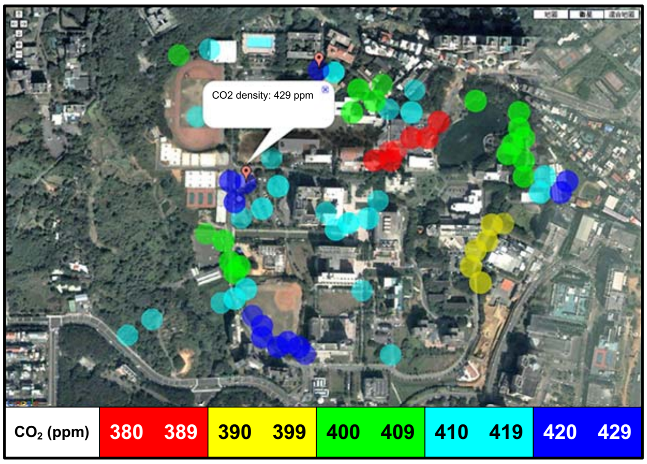

Fig. 4. A snapshot of CO$_2$ concentration at the NCTU campus.

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.

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