A Novel Vehicular Sensing Framework for Smart Cities

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***Abstract*—Smart cities leverage technology to analyze data to make decisions, anticipate problems and coordinate resources to operate efficiently. Data produced by sensors embedded in vehicles moving on streets enable sensing applications for smart cities that were infeasible in the past due to high deployment costs. In this paper, we propose a novel framework for collection, aggregation and retrieval of data. The framework considers vehicles and road-side units as the main entities. To collect data, the city road network is divided into a number of sensing regions. We discuss the aggregation operations for each type of event. A retrieval mechanism is also proposed to deliver content in real-time. The simulations results demonstrate that the proposed framework outperforms existing vehicular sensing approaches in terms of delay and accuracy.**

Keywords— aggregation; road-side unit; vehicular sensing.

I. INTRODUCTION

A smart city is a city which works in an intelligent sustainable way. This is possible by leveraging devices for monitoring and control to offer services and manage infrastructure in an efficient way. With the growth in the number of vehicles embedding a variety of on-board sensors, (e.g. GPS, speed sensors, chemical spill detectors, and sophisticated cameras), and with the advent of vehicular networking, vehicular event sensing provides a phenomenal opportunity for data intelligence in smart cities at virtually no device-deployment cost. Vehicular networking involves two major communication paradigms: V2V (vehicle-to-vehicle) and V2R (vehicle-to-roadside). The DSRC/802.11p standard has been used for specifying the medium access and physical layer characteristics for the communication protocols that have been designed for vehicular networks.

Vehicular sensing for smart cities is also particularly interesting first because vehicles are mobile, and therefore can cover large areas of the city. Second, vehicles have access to multimodal data. Vehicular sensing [3] can provide data which enables a diverse range of smart applications. Drivers in a city can be provided with congestion in a certain road segment [2] and free parking space availability. All this information saves a significant amount of travel time and enhances fuel efficiency. Vehicular sensing also offers a cost-effective solution for monitoring physical phenomenon. For example, with inherent mobility, vehicles can measure the dynamism in CO_2 variation [9] over a large region. Besides these applications, the presence of still/video cameras in vehicles makes vehicular sensing an attractive platform for smart surveillance applications [3] to promote a safer city life.

Proactive dissemination of sensed data suffers from significant packet collisions since data are periodically diffused by all vehicles. On the other hand, pulling of data on-demand requires precise knowledge of the entity to be searched. Without such knowledge, the network will be flooded with queries. In fact, storing and retrieving a pertinent past event is also a significant issue which need to be addressed.

In this paper, we propose an efficient and scalable framework for collection, aggregation and retrieval of sensed data. Basically, we divide the city (or a given region) into several sensing regions; each sensing region is associated with a road-side unit (RSU). Sensed data are collected at an RSU which aggregates them and creates usable summaries. The summaries are stored and provided on-demand when requested by a consumer.

II. RELATED WORK

The Self-Organizing TIS (SOTIS) [2] is one of the foremost contributions that address sensed data dissemination to provide traffic congestion status to drivers. In this contribution, each vehicle computes the average speed in all road segments within its transmission range and periodically disseminates traffic packets. Since, the packets are disseminated for long distances; large delay is incurred for far locations. As a result, drivers may take decisions much before they receive the traffic packets. In VITP [4], vehicles play two roles: virtual ad hoc server and VITP peer. VITP peers join the ad hoc server on demand. The virtual ad hoc server receives location based queries and executes them using its VITP peers. Once completed, the result is returned to the query initiator.

In Clustered gathering protocol (CGP) [5], sensed data is aggregated using clusters and uploaded to the road-side unit. The limitation of this protocol is that it is designed for a highway scenario and it only focuses on collection of data at server and does not address retrieval of sensed data directly by vehicular users.

We, however propose a vehicular sensing framework that addresses all aspects, namely collection of data originated by sensors, aggregation to create usable summaries and retrieval by consumers anywhere in the vehicular networks. Since data are not diffused, yet accessible by all consumers, the limitation of proactive dissemination is avoided. Since, all data are stored in road-side units; content originated in far locations as well as history data can be accessed efficiently by the consumers.

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III. VEHICULAR SENSING FRAMEWORK

A. Data collection, Aggregation and Storage

For collection of sensed data, we rely on RSUs which are deployed along major roads in a city. RSU communicates with a vehicle within its coverage range and is connected to the back-haul infrastructure. For our sensing framework, we consider a uniform mesh deployment policy [8] for RSUs.

1)Sensing Region Determination: The city is divided into a number of smaller sensing regions, where each sensing region has a dedicated RSU, called home-RSU which is used to gather data about events sensed within the region. Given the fact that a city can be viewed as a set of polygons formed by intersections and streets, sensing regions constituting one or more polygons can be easily determined. First, the polygons are identified. Then a home-RSU identification procedure is used to decides a home-RSU for each polygon. Polygons having common home-RSU form a sensing region.

a) Polygon Identification Procedure: The city road network is represented as a graph $G = (V, E)$, where each intersection is replaced by a vertex $v \in V$ and each road segment is replaced by an edge $e \in E$, where $E \subset V \times V$. A city road network contains many dead ends. Any edge connected to a dead-end is termed as dead edge. It is intuitive that if we remove all dead edges from graph G, then the resulting graph, G' can be viewed as a set of polygons. The polygons can be identified by enumerating all chordless cycles [6] in graph G'. A modified depth-first search procedure [6] is used to identify all polygons. Each polygon is designated by a vertex set P_i which contains vertices that constitute the polygon.

b) Home-RSU Identification Procedure: For a given polygon, its home-RSU is identified as follows. Shortest distance between all vertices of the polygon and all RSUs are determined by using Dijkstra's algorithm [1] after including RSUs as vertices in graph G. Then, for each RSU, a weight value is obtained. The weight is used to select the home-RSU among all RSUs. It is given by the shortest distance between the farthest vertex on the polygon and RSU. The farthest vertex is the vertex having largest value of shortest distance. Each RSU is represented by an ID and position. The weight of an RSU denoted as RSU_j for a polygon P_i is given as:

$$W(P_i, RSU_j) = \max_{u \in P_i}\{MinDist(Pos(u), Pos(RSU_j)\} \qquad (1)$$

Where, $Pos(u)$ and $Pos(RSU_j)$ denote the position of the farthest vertex u of polygon P_i and position of RSU_j respectively. After obtaining weights for all RSUs, the RSU with smallest weight is decided as the home-RSU for polygon P_i. The reason behind the selection criteria for home-RSU is that the vehicles that sense events in the streets of the polygon can send data to the home-RSU with lower delay. An RSU can be selected as home-RSU by more than one polygons. Thus, at the end of the procedure, polygons having common home-RSU form a sensing region. Note that, some of the polygons that belong to two different sensing regions can have common edges. As shown in Fig. 1 (a), the common edges indeed appear along the borders of two sensing region. These edges must be included in either of the sensing regions that share them. We follow a simple rule for the inclusion, in which the common edge is added to the sensing region having smaller value of total road distance. Note that the dead edges removed at the beginning of the procedure are added back to the sensing regions, in which they are physically located.

Since the sensing regions are pre-determined, each vehicle that enters the network can determine in which sensing region it is located with the help of digital map and its position.

2)Event Sensing and Collection: Each type of event is associated with a position and timestamp of the occurrence of the event in addition to specific details. For example, details of a traffic event includes speed and movement direction of a vehicle. The events are sensed at a periodic interval, referred to as sensing interval. The sensed reports are stored in local cache of a vehicle and are sent to the home-RSU at a regular interval, called as reporting interval. For example, CO2 monitoring requires a reporting interval of 5 minutes [9], on the other hand the traffic information need to be sent once in every second. Similarly, from the sensing perspective, the CO2 concentration is sampled every 3 seconds [9]; whereas the measurements for on-street parking space need to be taken every 50ms [10]. At the end of reporting interval, the sensed data are sent to the home-RSU. Since the position of home-RSUs are known, unicast routing is used.

Also, the destination is a fixed node and hence routing is free from mobility related issues which occur if the destination is mobile. For unicast routing, we rely on the intersection-based routing protocol, BAHG [7] proposed for urban scenarios. In BAHG, the routing path is given by a sequence of intersections and is determined based on hop-count (to avoid longer path) and connectivity (to avoid sparse region) of road segments. The sensed data is forwarded by intermediate forwarders. When a forwarder finds itself within the coverage range of home-RSU, it transmits the data directly to the home-RSU. Fig. 1 (b) shows uploading of data by vehicle A and vehicle B to the home-RSU of a sensing region.

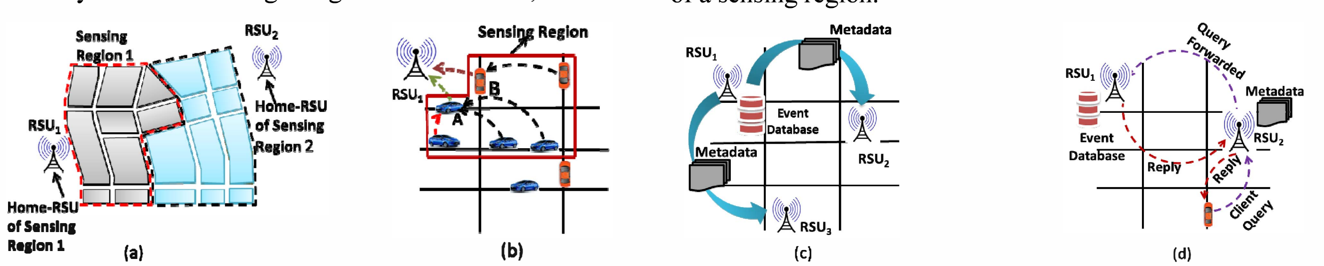

Fig. 1. (a) Determination of sensing regions, (b) Collection of data about sensed events, (b) Metadata sharing among RSUs, (c) Retrieving data of sensed event

3) Aggregation: When, home-RSU gathers data of sensed events, it performs aggregation. Aggregation functions has been defined in the literature for many sensing applications. For traffic related events, simple functions such as SUM (total number of vehicles), MAX (maximum speed of vehicles), AVG (average speed of vehicles) are used to obtain finer details about traffic of a road segment. Similarly, for surveillance applications, image processing algorithms can be used to enhance the street view. As far as CO2 monitoring is concerned, the measurement data are aggregated to create summaries that can be used to identify the temporal and spatial variations of CO2 concentration.

4) RSUs as Storage : The use of RSUs as a storage entity for sensed events enhances the possibility of obtaining knowledge of past events such as street images captured in a previous week or number of accidents in last month. In addition, storing data at a fixed place avoids the need to flood the entire network with queries in order to search for the desired content.

5) Metadata Sharing among RSUs: To obtain information about an event, consumers have to specify time and location of the event. Since, data about events are stored in home-RSU of the sensing region in which the event has occurred, a consumer needs to be aware of the home-RSU to look for. However, consumers are unaware of the data stored in various home-RSUs. As a result, unnecessary exchange of request and reply takes place when the requested content does not exist in home-RSU. To address the above issue, we allow home-RSUs to exchange metadata with each other. As shown in Fig. 1 (c), RSU_1 shares its metadata with RSU_2 and RSU_3. In the context of sensing, metadata describes some of the features of the data. In particular, metadata includes time, location and type associated with data of a stored event. As we will see in next section, with metadata sharing, time wasted in communication when data is not located in the home-RSU can be significantly saved. Furthermore, consumers can obtain suggestions that influence their choice of events, involving less number of communications.

6) Retrieving Data In the vehicular sensing framework, consumers initiate queries to retrieve data about an event of interest. The framework supports a diverse range of queries. To retrieve data, consumer initiates queries to the nearest home-RSU. The query specifies the time, location and type of event. The nearest home-RSU searches its database based on the specifications. If a match is found, it sends a reply containing the requested content back to the consumer. If the requested content is not found, the home-RSU searches in the metadata that it has received from other home-RSUs. If metadata of an event matches the query specifications, the home-RSU infers that event has been stored in the home-RSU of the event being requested. The nearest home-RSU thus communicates with the home-RSU of the event asking it to reply with the required data of the event. On receiving reply, the nearest home-RSU forwards it to the consumer. If no metadata is found for the requested content, the nearest home-RSU formulates a list of related events based on its metadata and the query. The list is sent to the consumer. The list contains information about events similar to the event of interest. Thus, a consumer can have choices to look for a related event. For example, a consumer initiates a query "What is the parking statistics in area A from 10 A.M to 11 A.M". If this information is not available, the nearest home-RSU extracts related events from the stored metadata such as "parking statistics available for area A from 11 A.M to 2 P.M" and "parking statistics available for area B from 10 A.M to 1 P.M". These suggestions help the consumer to decide his parking action. Query and reply messages between consumer and the nearest home-RSU are exchanged using unicast routing [7]. The message exchange during data retrieval is shown in Fig. 1 (d).

IV. PERFORMANCE EVALUATION

In this section, we investigate the performance of the proposed vehicular sensing framework which we refer to as Vehicular Sensing Framework for Smart Cities (VSFSC). We used NS-2 simulator to implement the proposed scheme. The framework is compared with well-known approaches for vehicular event sensing: SOTIS [2] and VITP [4].

A. Simulation Setup

Our Simulation scenario is shown in Fig. 2. It represents an area of 3000m x 3000m of Montreal city and is extracted from the OpenStreetMap database. In Fig. 2, we assume presence of six RSUs and the sensing regions are obtained using the procedure described in Section-III.A.1. The SUMO (Simulation of Urban Mobility) is used to generate vehicle movements. Maximum velocity of a vehicle varies from 5 to 35 m/s in steps of 5 m/s. Transmission range is set to 300m. IEEE 802.11p is used as MAC and PHY (3 Mbps data rate). TwoRayGround Model is used as the channel propagation model. Size of data packet (sensed data), query packet and reply packet are set to 100 bytes, 50 bytes and 200 bytes respectively. We evaluate the vehicular sensing framework by considering traffic events (with 1 sec reporting interval). A vehicle can obtain traffic summaries (e.g., congestion status of a road segment) by originating a query. The performance metrics used are: 1) Access Time: it is defined as the time elapsed between a query is initiated and the desired content is received, 2) Information accuracy (%): it is defined as the difference between the estimated value and the actual value of a traffic data, 3) Query Success Rate (%): it is the ratio of the number of queries for which the response is obtained successfully to the total number of queries disseminated.

B. Results and Discussions

Fig. 3(a) shows that the access time increases with the number of consumers. This can be explained by increase in the number of packet collisions. VSFSC shows the lowest access time; more importantly, it is scalable as its performance is not impacted by the number of consumers. In contrast, in case of SOTIS and VITP, the access time increases considerably with the number of customers. SOTIS has higher access time as it is proactive in nature and congestion occurs with an increased number of connections. Though VITP is reactive in nature, its access time is higher than VSFSC as the former requires some time period to establish the virtual infrastructure in the target area. Fig. 3(b) shows that the access time increases with the query distance. Unlike Fig. 3 (a), the high rate of changes in access time is due to the fact that hop count increases with the increase in query distance. SOTIS has suffered the worst delay as it involves redundant message exchanges. VSFSC achieves the smallest access time since the latest data stored in RSU is provided to the consumer in no-time.The server setup time of VITP has a big role in the total access time; therefore, VITP performs worse than VSFSC. Information accuracy is shown in Fig. 3(c). For all three schemes, VSFSC, VITP and SOTIS, the accuracy decreases with the increase of vehicle density. Indeed, the higher the number of vehicles, the larger is the bandwidth required to send individual speed. Thus, with the increase in density, packet collisions increase. As a result, the average speed is computed by insufficient information. It is noticed that the impact of vehicle density on information accuracy is lowest in case of VSFSC. This can be explained by the fact that each vehicle uses unicast rather than broadcast to send the sensed data to the home-RSU. On the contrary, SOTIS and VITP use broadcast which is highly unreliable in high density scenarios.

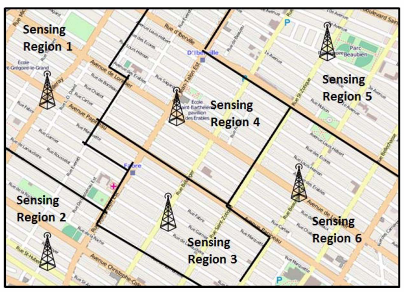

Fig. 2. A region of Montreal city (3000 X 3000 meter^2)

Fig. 3 (d) shows the impact of query distance on query success rate. Query distance is the shortest distance between the consumer and RSU that stores the desired content. It is observed that VSFSC achieves a consistent success rate of around 97 % and is not impacted by the query distance. The rationale behind the significant success rate of VSFSC is (1) the metadata is shared with other RSUs: this provides the consumer a flexibility to locate the content; and (2) sensed data is collected at regular intervals. Once a query is intiated, the most recent data is extracted from an RSU and is provided to the consumer. Indeed, no extra efforts, in terms of packet exchanges, is required between query origination and reply dissemination. As the sensed data is updated in real-time , the consumer can rely on the received data to take further action. It is also observed that VITP suffers a severe degradation in query success rate when query distance increases; this can be explained by the fact that the difficulty in resolving a consumer's query increases as the distance between consumer and the event increases, which eventually results in dropping the query.

V. CONCLUSION AND FUTURE WORK

In this paper, we present a novel sensing framework for smart cities that uses vehicles to sense events occurring on streets. The objective of the framework is to provide drivers with traffic related data to plan their route. It can be also used in other key applications such as air pollution monitoring, street imaging and parking discovery, etc. In future, we plan to integrate cloud technology in the framework to extend its usability beyond vehicular network.

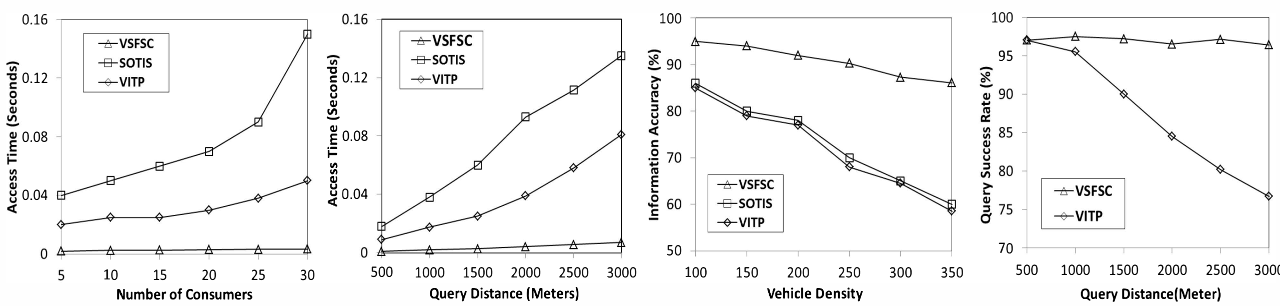

Fig. 3 (a) Access time Vs No. of consumers, (b) Access Time Vs Query distance, (c) Information accuracy Vs veh. density, (d)Query success rate Vs Query Dist.

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