V-Radar: A Traffic Query Protocol For Urban Environments

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Introduction

• Road build-ups and congestion have an adverse affect in modern societies
  • Environmental Pollution
  • Millions of wasted money /hours
  • Commuter Stress

• Cost of traffic delays (US, 2011) estimated to:
  • $100 billion
  • Delay endured by average commuter
    • 34 hours

• Numbers expected to increase significantly over the next years.

Introduction

- Commodization of low-cost, high quality electronic circuitry.
- Near-omnipresence of sensory and communication technologies.
- Automobile environment no exception to this norm.
  - Location, Speed, Acceleration, Breaking sensors, etc.
- Inter-Vehicle Communication (IVC)
- Reduce effects of congestion via dissemination of such sensory information to other vehicles.
Introduction – Novelty

V-Radar: A vehicular traffic information query protocol for urban environments based on V2V communication

• Enable the querying of traffic information along a composite road-path, from the vehicle’s current position towards final destination.
• Also query alternate road-paths to the destination.

• Allows driver / navigation system to establish a broader and complete view of traffic conditions that will be encountered further ahead.

Valuable information when calculating optimal path to destination in terms of travel time.
Current Approaches

- **SOTIS**\(^1\) and **TrafficView**\(^2\): Periodic beacon broadcast for traffic congestion estimation.
- **StreetSmart**\(^3\): Same as above but clustering and epidemics for information dissemination.

**Problem:** Proactive techniques – fail in large and dense VANETs – quadratic data increase.

- **Road Network Based Adaptive Query Evaluation:** Adaptive query evaluation plan based on road topology. Vehicles participate in traffic query resolution based on their position in the road.

**Problem: 1)** Caters only for querying traffic flow of a singular road. High network overhead if to apply for querying a composite road-path. 2) Use of control packets – additional overhead.

System Model - Assumptions

• Consider an urban environment.

• Driver and occupants want to minimize travel time en-route to destination.

• Vehicles communicate in a V2V mode.

• Each vehicle periodically broadcasts a beacon message (CAM) of the form:

  \[ Bcn_i (Time, V_{uid}, Pos, Spd, Hdg, R_{uid}) \]
System Model - Assumptions

• Road topology information stored on-board preloaded maps.
  • Geographic Location obtained via GPS
  • Maps are enriched with historical traffic statistics

• Each vehicle includes a local cache
  • Temporal storage for traffic information

• Traffic Information sensed through received beacons from roads that have been traversed.
  • Create a new record in cache upon entering a road.
  • Update respective record based on $R_{uid}$ value in beacons.
System Model - Assumptions

- To follow the shortest path to destination in terms of geographic distance is naïve.
  - No guarantee for reduction in total commute time
  - Traffic conditions probably dictate otherwise.

- A vehicle can provide the driver / navigation system with the information to make optimal travel decisions.

- Issue location-dependent traffic queries to other vehicles - Geocast.
System Model – The V-Radar Concept

• Support the generation and dissemination of traffic queries in a manner that resembles a forward-scan radar. Similar concept to:
  • Aviation Radar Systems
  • Maritime Radar Systems

• Detect obstacles that might block the normal course of a vessel or an aircraft

For V-Radar such obstacles are traffic build-ups and congestion
System Model – The V-Radar Concept

- Follow the path to Destination with the minimum travel time
- X would like to know the traffic conditions on other available road-paths
- Urban topology known – calculate K alternate paths
- Rank K paths based on geo-distance from next intersection.
System Model – The V-Radar Concept

- Issue LookAhead (L) queries with Query Rate (R) towards all K road-paths.
- L queries – radar pulses
- Directional queries that propagate to a certain depth L in each of the road-paths
- Collect traffic conditions in all roads up to and including the specified depth.
Example

Query road traffic on Road-Paths towards Destination up to $L = 2$
System Model – Problem Formulation

• Consider Road Network as directed graph

\[ G = \{V, A\} \]

\[ V = \{u_i\} \text{ - intersections} \]
\[ A = \{a_{ij}\} \text{ - roads} \]

• Path \( P_{ij} \): a unique, alternate sequence of connected nodes (intersections) and arcs (roads) in \( G \).

\[ P_{ij} = \{i, i_1, i_2, \ldots, i_k, j\} \]

• \( D(P_{ij}) \): length of Path \( P_{ij} \)

• \( P \): set of paths that can be defined in \( G \) from \( v_i \) to \( v_j \)
System Model – Problem Formulation

• $t_{pij}$: Travel time from from intersection $u_i$ to $u_j$ in any path $P_{ij}$

• Travel time influenced by:
  • Static conditions (i.e. road length)
  • Dynamic conditions  (average speed, vehicle density, traffic light queue..)

• Therefore identify set $S$ of $P_{ij}$ from $u_i$ to $u_j$:

$$S = \left\{ P_{ij}^1, P_{ij}^2, P_{ij}^3, ..., P_{ij}^k \right\} \subseteq P$$

$$\text{s.t}$$

$$\forall n \in \{1, ..., K - 1\}, \forall n \in \{1, ..., K - 1\}$$
System Model – Problem Formulation

• Naïve assumption
  • Calculate all shortest paths and transmit traffic queries towards them to acquire information.

• However we have constraints:
  • Query-Reply delay threshold,
  • Size of road topology,
  • VANET connectivity status
  • ....

• Querying:
  • all $P_{ij}$ in $P$
  • all roads (up to length D) in any $P_{ij}$

**Not scalable**

High probability to lead to inaccurate or out-of-time results
System Model - Objective

• To meet previous constraints, vehicles should be able to estimate
  • Number of K paths
  • Depth L for each P_{ij}
  • Query rate R for prudent use of wireless channel

Provide mechanisms that enable:

• Sustainability of an acceptable traffic query-reply delivery rate and ensuring any delay thresholds are met.
• Maximization of the number of alternate road-paths (\text{max}(K)) and roads (\text{max}(L)) to be monitored,
• Minimize wireless transmissions and bandwidth utilization.
Architecture

- Modular Architecture
  - 6 inter-connected modules

- V-Radar, runs on the Application layer.

- Utilizes underlying routing and transport protocols.

- Interfaces with vehicle’s sensor manager.
Architecture

Road-Path Span (K) Estimator

- Identify how many road paths to destination will be queried.
- Interface with Nav. System for road topology and travel preferences of driver.
- Utilized also information from Traffic Information Cache – adjust K based on stored replies from previous queries.
Architecture

Look-Ahead (L) Estimator

- How deep a road-path will be queried?
- Crucial for information accuracy / correctness
  - Too shallow -> Horizon Effect
  - Too deep -> Probability of packet loss or high reply delay.
Architecture

Query Rate (R) Estimator

- For updated traffic information periodic query generation required
- Following constraints need to be considered:
  - Vehicle speed
  - Road length
  - Number of neighbor vehicles
- Adjust Query Rate (R) adaptively. Similar concept to ATB.
Architecture

Data Aggregation Module

- Several identified K-Paths might be overlap -> Duplicated queries -> unnecessary channel utilization
- Identify such situations
- Query Information (reply) aggregation in single messages.
Architecture

Traffic Information Cache (TIC)

- Store traffic information (speed / density) about roads

- Each cached item is a 4-tuple: 
  \[ id, \text{timestamp}, \text{data-type}, \text{value} \]
  - \( id = r_{uid} \)
  - Data-type = speed || density
  - Value = Sensed traffic info

- A Cache Replacement Module (CRM) enforces stale object handling policies (LRU, MRU, etc.)
Architecture

Query Manager
• Orchestrates operation of other components and create a query message

• Define a Query / Reply Message Format

• 16-byte fixed header

• Variable-sized payload (data) section

C: Append cached data to reply?
R: Query-Reply?
A: Can a vehicle append data to a reply?
Evaluation - Setup

- V-Radar Application module for **ns-3.11**
- Compare against method **Road Based Adaptive Query Evaluation** (RNBAQ)
- **Realistic Mobility** – TAPAS Cologne - 4x3 Km area
- **200** random selected vehicles
- Queries for **800s**
- Data Dissemination Protocol : **VADD**
- K,L,R values are set manually (still researching techniques for estimators)
  - K = 3
  - L = 1 - 7
  - R = 0.1 – 1.0 pkts/sec
Evaluation – Preliminary Results

- Lower Network Overhead than RNBAQ for all values of L
- V-Radar utilized a single packet for a composite road-path query
  - RNBAQ generates query for each road + control packets
- Stable overhead over different values of query generation rate (R).
### Evaluation - Preliminary Results

- **Shallow V-Radar PDR drop** – less packet collisions – less dropped messages.
- **Improved PDR over RNBAQ** due to TIC – high probability to answer queries from other vehicles’ cache. No need to query traffic up to road L.
- **Faster query return time**, packet TTL not reached
- **Accuracy overall better** than RNBAQ – reduces with L increase.
Conclusions and Outlook

- **V-Radar** – Traffic query protocol using V2V communication
- Ability to monitor traffic conditions on several composite road-paths
- Preliminary results show significant improvements over related schemes.
- Analytical models for estimating Query Rate (R) for better wireless channel utilization
- Investigate intelligent caching techniques and adaptive CRM - provide improved information accuracy.
- Data Aggregation models for in-network traffic query/reply aggregation.
Questions

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