Catch-Up: A Data Aggregation Scheme for VANETs

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Outline

- Introduction
- Related Work
- Distributed coordinated aggregation
- Analysis for upper bound of overview report
- Simulation
- Conclusion
Introduction

- Traffic Information Dissemination
  - Each vehicle periodically detects the traffic conditions around it, and then, forwards the information to vehicles following behind it
  - Like congestion detection

- Redundant Data & Limited Bandwidth
  - Multiple redundant copies for the same traffic status
  - Consuming a considerable amount of bandwidth
Related Work

- **Two aspects**
  - Routing-related (our focus)
    - How two reports can meet each other at the same time at the same node
  - Data-related
    - Coding, calculation, and compression of aggregatable data

\[
\begin{align*}
  v_1 \quad r^1 (30\text{mph}) \quad v_2 \quad r^2 (35\text{mph})
  &\quad v_3 \quad r^3 \leftarrow r^1 + r^2 \\
  ((30+35)/2=32.5\text{mph})
\end{align*}
\]
Routing-related

- **Structured Aggregation**
  - A routing structure, forwarding tree, is maintained to ensure reports can be forwarded to the same node at the same time
  - Widely used in sensor networks, but **infeasible in VANETs**
Structureless Aggregation

- Randomized Waiting
  - Wait for a random period before forwarding to the next hop
  - During the waiting period, more reports can be received and aggregated

- Periodical Waiting
  - Wait for a fixed period before forwarding to the next hop

We adaptively change the forwarding delay of individual reports
Distributed coordinated aggregation

- Two Properties
  - Channel Eavesdropping
    - Every node is able to receive reports being transmitted in the channel and log them into its local database
  - Traffic Information is delay-insensitive
    - Even a delay of tens of seconds is still acceptable
    - Give us an opportunity to trade off increased delay for reduced communication overhead
System Model

- Aggregatable Reports
  - Generated by a change in traffic condition
  - Define event frame as $< p_1, p_2, t_1, t_2 >$
  - Generate an overview report for all aggregatable reports

- Data Dissemination
Insert a delay before forwarding a report to the next hop by local observation

$ r^1 $ is ahead, so $ r^2 $ should speed up and catch up with $ r^1 $
Distributed MDP Model

- $s$ – world state
- $a$ – action
- $\Pi$ – Decision Maker
Decision Tree

To find the optimal policy $\pi = (a_0, a_1, a_2, \ldots), a_i = (\text{WALK}, \text{RUN})$
Expected Future Reward

- **Objective**
  - To find a policy which maximizes the expected future reward

- **Policy** $\pi$
  - **Sequence of actions** to be performed for a given report in the future
  - $\pi = (a_1, a_2, \ldots, a_t, \ldots)$, each element is an action of (WALK, RUN)

- **Expected Future Reward**
  - $R_b(\pi) = \sum_{t \geq 1} \gamma^t \sum_{1 \leq j \leq q} b(r^j, p_t) w_t(r^i, r^j)$
  - where $\gamma$ is a future discount factor and $w_t$ means the expected reward at time $t$ (the saved communication overhead due to aggregation of the reports)
Virtual Report – $r^0$

- To encourage some reports to slow down (WALK)
- Probability that report $r^i$ and $r^0$ meet at time $t$

$$b(r^0, t) = \int_{t_2 \in [t, t+1]} \text{arr} \left( \frac{vRUN - \bar{v}}{vRUN} t_2 \right) dt_2$$

Internal States

- $(r^0, r^1, r^2, r^2, \ldots)$
Analysis

- All reports from a given road section and from a given time period can be aggregated into an overview report.
The convergence time upper bound:

$$T_{cvg} \leq \frac{(p_2 - p_1) v_{RUN} + (t_2 - t_1) v_{RUN} v_{WALK}}{v_{WALK} (v_{RUN} - v_{WALK})}$$

The convergence distance upper bound:

$$D_{cvg} \leq \frac{(p_2 - p_1) v_{RUN} + (t_2 - t_1) v_{RUN} v_{WALK}}{v_{WALK} (v_{RUN} - v_{WALK})} \cdot v_{WALK}$$

The total latency upper bound:

$$T_{dism} \leq \max(T_{cvg}) + \frac{D_{dism} - \max(D_{cvg})}{v_{FLY}}$$
Simulation

- Based on NS2 and GrooveNet
- Compared to Randomized Waiting (RW)

<table>
<thead>
<tr>
<th>Table 1: Simulation Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Parameter</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Road Length</td>
</tr>
<tr>
<td>Vehicle Number</td>
</tr>
<tr>
<td>Road Section Length</td>
</tr>
<tr>
<td>Time Frame</td>
</tr>
<tr>
<td>Communication Range</td>
</tr>
<tr>
<td>MAC layer</td>
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<tr>
<td>Mobility Model</td>
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<tr>
<td>Trip Model</td>
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</tbody>
</table>
## Results

- **CATCHUP(100,1000)** - walking speed at 100m/s, running speed at 1000m/s
- **CATCHUP(200,2000)** - walking speed at 200m/s, running speed at 2000m/s

![Graph showing packet distribution over distance](image)

<table>
<thead>
<tr>
<th>Protocol</th>
<th>TotalTrans</th>
<th>MaxCvgDist</th>
<th>MaxCvgTime</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATCHUP(100,1000)</td>
<td>1204</td>
<td>4.4km</td>
<td>44s</td>
</tr>
<tr>
<td>CATCHUP(200,2000)</td>
<td>1231</td>
<td>7.6km</td>
<td>38s</td>
</tr>
<tr>
<td>Randomized Waiting</td>
<td>1944</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
- CATCHUP trades increased delay for reduced communication overhead

- For CATCHUP, the delay mainly reside within the first 4 km

- For Randomized Waiting, the delay is linear
Conclusion

- We introduced a idea of adaptively controlling forwarding delay in data aggregation in VANETs.
- Aggregation is a tradeoff between delay and communication overhead.
- One problem is what are the optimal delay values for WALK and RUN for our scheme.
Other Issues

- Report Overtaking
How to judge whether a report is contained by another aggregated report?

\[ r^1 \in r^3 \quad \text{where} \quad r^3 = r^1 + r^2 \]

Bloom Filter

- A space-efficient probabilistic data structure that is used to test whether an element is a member of a set
- Each report is attached with a bloom filter table, which includes information of all merged report
Some problems

- Each vehicle can only obtain a partial observation of the world

- We cannot introduce much extra communication overhead for node coordination
Action \( a \) : WALK, RUN
  - The propagation speed of a report
  - Two different delays before forwarding to the next hop

Observation \( o \) : eavesdropped reports
  - Tuple <report, time_stamp, action(WALK/RUN)>

Internal state \( b \) : estimated position of reports
  - \( b(r, p_t) : \) Probability that report \( r \) is at position \( p \) at time \( t \)