VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks

Final Presentation

Christopher Dorner

August 4th, 2008
Introduction

Vehicle Assisted Data Delivery

The VADD Delay Model

The VADD protocols

Performance evaluation

Summary, Conclusion, Additional Slides
Introduction
In delay tolerant applications (DTN), we want

- To make a reservation in a restaurant
- To query parking information for a better road plan
- To query a department store when going shopping

Thus, we want

- To deliver a message from a moving source to a stationary site (e.g. infostation)
- Through the existing vehicular network
- As fast as possible (select forwarding path with smallest packet delivery delay)
VANETs are

- Highly mobile
- Frequently disconnected
- Network density depends on traffic density
  - High in cities
  - Low in rural areas
  - Higher during the day than during the night
A vehicle knows its own position

Vehicles communicate through short range wireless channel (100m - 250m)

A vehicle knows its neighbors positions by beacon messages (one hop)

- Beacon messages contain velocity
- Beacon messages contain direction (not final destination!)
- Beacon Messages contain location (GPS coordinates)

Vehicles are equipped with digital maps (road information and traffic statistics)

A Vehicle defines the packet header (TTL in seconds, source id, destination id, ...)

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- Vehicles communicate through short range wireless channel (100m - 250m)
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- Vehicles are equipped with digital maps (road information and traffic statistics)
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What we want to do
Challenges
Preconditions and Assumptions
Example: Digital Map
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Real-time traffic statistics of New York City (07/26/08) Copyright Yahoo Maps

**Red road** speed approx. 0 mph  
**Yellow road** speed approx. 30 mph  
**Green road** speed approx. 55 mph
Vehicle Assisted Data Delivery

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Three Basic Principles
Geographical Greedy - not good for sparse VANETs
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- Existing protocols like
  - AODV
  - DSDV
  - DSR

- rely on existing end-to-end connections
- Otherwise, packets will be dropped
- Not suitable for highly mobile ad hoc networks like VANETs
- Also not suitable for sparse networks
Proposed VADD follows three principles

1. Use wireless transmission as much as possible
2. Always choose the road with highest speed (lowest expected data delivery delay)
3. Continuous execution of dynamic path selection during packet forwarding process

And makes use of

- Idea of carry and forward
- known traffic pattern/road layout (limits vehicle mobility)
Geographical Greedy - not good for sparse VANETs

- Road from $I_a$ to $I_b$ is geographically shortest path
  - But: no cars on the road $\rightarrow$ no wireless transmission

- from $I_a$ to $I_b$ via $I_c$ and $I_d$ longer path
  - But: many cars on the road
  - Much faster wireless transmission possible
**The VADD modes**

**Intersection Mode**
Select probabilistically best forwarding direction

**StraightWay Mode**
Greedy (geographical) forwarding strategy towards next target intersection

**Destination Mode**
Broadcast packet to destination
Two Problems
- Where to go?
  - The VADD Model (minimum data delivery delay)
- Which carrier?
  - The VADD Protocols
The VADD Delay Model

packet forwarding delay between two Intersections

First idea
Intersection mode: Which direction to go?
Boundary?
Linear Equation System
Example

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packet forwarding delay between two Intersections

- $r_{ij}$: Road from Intersection $I_i$ to $I_j$
- $l_{ij}$: Euclidean distance of $r_{ij}$
- $p_{ij}$: Vehicle density on $r_{ij}$
- $v_{ij}$: Average vehicle velocity on $r_{ij}$
- $d_{ij}$: Expected packet forwarding delay from $I_i$ to $I_j$
- $R$: Wireless transmission range
- $c$: Average one hop packet transmission delay

\[
d_{ij} = (1 - \exp^{-R \cdot p_{ij}}) \cdot \frac{l_{ij} \cdot c}{R} + \exp^{-R \cdot p_{ij}} \cdot \frac{l_{ij}}{v_{ij}}
\]

- Indicates, that inter-vehicle distances are smaller than $R$ on a portion of $1 - \exp^{-R \cdot p_{ij}}$ of the road, where wireless transmission is used.
- On the rest of the road: vehicles are used to carry the data.
- Larger traffic density make less portion completed by vehicle movement.
First idea: represent VANET as a weighted and directed graph

**Nodes**  Represent Intersections

**Edges**  Represent the roads connecting the intersections

**Weight of Edges**  The forwarding delay between Intersections

**Direction of Edges**  Represent the traffic direction

Idea: Apply *Dijkstra’s Algorithm* to find shortest path from source to destination
First idea: represent VANET as a weighted and directed graph

**Nodes**  Represent Intersections

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**Direction of Edges**  Represent the traffic direction

Idea: Apply *Dijkstra’s Algorithm* to find shortest path from source to destination

**Would not work, because**

- No free selection of outgoing edge possible
- Only road with vehicles on it can be candidate for forwarding path
- Use stochastic model instead to select next road
Intersection mode: Which direction to go?

$D_{ij}$ \hspace{1cm} Expected packet delivery delay from $I_i$ to the destination through road $r_{ij}$

$P_{ij}$ \hspace{1cm} Probability, that packet is forwarded through road $r_{ij}$ at $I_i$

$N(j)$ \hspace{1cm} Set of neighboring intersections of $I_j$

Now compute $D_{ij}$ for each Intersection within boundary

$$D_{ij} = d_{mn} + \sum_{j \in N(n)} (P_{nj} \times D_{nj})$$

- Generates linear equation system of size $n \times n$ ($n$: number of roads within boundary)
- Can be solved in $\Theta(n^3)$ by applying Gaussian Elimination Algorithm
- Output: Priority list of outgoing directions for packet forwarding
Computation of delay involves unlimited unknown intersections.

Therefore, computation is impossible.

Solution: place a boundary including source and destination.

- Then, number of intersections is finite.
- Now the expected minimum forwarding delay can be found.

This paper: boundary is a circle.

- Center Point: destination
- radius: 4000 meters, IF distance to destination < 3000 meters
- ELSE: radius = distance + 1000 meters
Linear Equation System

- Rename the
  - Unknown $D_{ij} \rightarrow x_{ij}$
  - Subscript $ij$ of $d_{ij}$ and $x_{ij}$ $\rightarrow$ unique number for each $ij$
  - Subscript of $P_{ij}$ by its position in the equations

- $n$ linear equations with $n$ unknowns $x_1, x_2, \ldots, x_n$

$$ (P - E) \cdot X = -D $$

- One unique solution
- Solution is $D_{ij}$ for current $I_i$
- Sort $D_{ij}$ for each neighboring Intersection $I_j$

$$ P = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \cdots & P_{nn} \end{bmatrix}, \quad X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}, \quad D = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{bmatrix} $$

$$ E = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} $$
\[ D_{ac} = d_{ac} \]
\[ D_{ab} = d_{ab} + P_{ba} \cdot D_{ba} + P_{bc} \cdot D_{bc} \]
\[ D_{ba} = d_{ba} + P_{ab} \cdot D_{ab} + P_{ac} \cdot D_{ac} \]
\[ D_{bc} = d_{bc} \]
\[ D_{cb} = 0 \]
\[ D_{ca} = 0 \]
The VADD protocols

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Intersection Forwarding
L-VADD: Location First
L-VADD: Loops
D-VADD: Direction First
H-VADD: Hybrid
Performance evaluation
Summary, Conclusion, Additional Slides
Now priority list is available

But: which carrier should we choose?

Difficult: need to consider mobility and location

Leads to different intersection protocols:

- Location First VADD: L-VADD
- Direction First VADD: D-VADD
- Hybrid VADD: H-VADD
L-VADD: Location First

- Simple solution:
  - Select closest carrier towards preferred direction
  - Moving direction of chosen carrier does not matter
  - Example figure: \( A \rightarrow B \)

- Can reduce hops (minimize forwarding distance)
- Possibility of forwarding loops
L-VADD: Loops

Loop-free solution:
- Check previous hops
- No forwarding to these hops
- Could prevent good carriers from being selected

Loops have negative impact on delivery ratio
D-VADD: Direction First

- Direction First
  - Only consider carriers moving towards preferred direction
  - Choose closest one towards this direction as next hop
  - Example figure: $A \rightarrow C$

- No Forwarding Loops (Want to see proof? - additional slide)
- But: delay may be higher
Hybrid of L-VADD and D-VADD

- Try L-VADD first
- If it fails, e.g., Loop detected:
  - Switch to D-VADD

Combines advantages of L-VADD and D-VADD
Performance evaluation
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Delivery Ratio

Delay

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Metrics

- Delivery ratio
- Delay
- Network traffic

Compared with

- GPSR (with buffers*)
- Epidemic Routing

*buffers: extend GPSR to a simple carry-and-forward protocol

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation area</td>
<td>4000m × 3200m</td>
</tr>
<tr>
<td># of intersections</td>
<td>24</td>
</tr>
<tr>
<td>Intersection area radius</td>
<td>200m</td>
</tr>
<tr>
<td>Number of vehicles</td>
<td>150, 210</td>
</tr>
<tr>
<td># of packet senders</td>
<td>15</td>
</tr>
<tr>
<td>Communication range</td>
<td>200m</td>
</tr>
<tr>
<td>Vehicle velocity</td>
<td>15 - 80 miles per hour</td>
</tr>
<tr>
<td>CBR rate</td>
<td>0.1 - 1 packet per second</td>
</tr>
<tr>
<td>Data packet size</td>
<td>10 B - 4 KB</td>
</tr>
<tr>
<td>Vehicle beacon interval</td>
<td>0.5 sec</td>
</tr>
<tr>
<td>Packet TTL</td>
<td>128 sec</td>
</tr>
</tbody>
</table>
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Delivery Ratio

150 nodes

210 nodes
Delay

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150 nodes

210 nodes
Total data packets generated per second

- Data sending rate
- Data sending rate

210 nodes

Network Traffic

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Summary, Conclusion
Summary, Conclusion, Additional Slides
- VADD uses idea of carry-and-forward
- Make use of predictable vehicle mobility (known street-layout)
- Probabilistic Model and Linear Equation System for computing priority list
- Simulation shows that the VADD protocols have better performance than existing solutions in DTN
- H-VADD has best performance among all VADD protocols
Future Work and Conclusion

■ Future Work

☐ How to send replies?
☐ More efficient placement of boundary
☐ Consider Privacy and Security aspects in VANETs

■ Conclusion

☐ Very good approach to solve problem of connection problems
☐ Very high delivery ratio (drop only of time limit reached)
☐ Fast (low Delay in performance evaluations)
Thank you for your attention

Any Questions?
Proof by contradiction: D-VADD is loop-free

Routing loops occurs between nodes A and B. A passes packet to B and B passes it back to A

- First Case
  - A and B move in same direction
  - Forwarding from A to B indicates, that B is closer towards preferred direction
  - Passing back indicates the reverse
  - **Contradiction**

- Second Case
  - A and B move towards different directions
  - Forwarding from A to B indicates, that B is moving towards direction with higher priority
  - Passing back indicates, that A’s direction has higher priority
  - **Contradiction**

Therefore: no loops in D-VADD