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

Final Presentation

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Introduction

Vehicle Assisted Data Delivery

The VADD Delay Model

The VADD protocols

Performance evaluation

Summary, Conclusion, Additional Slides

Introduction

What we want to do

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)

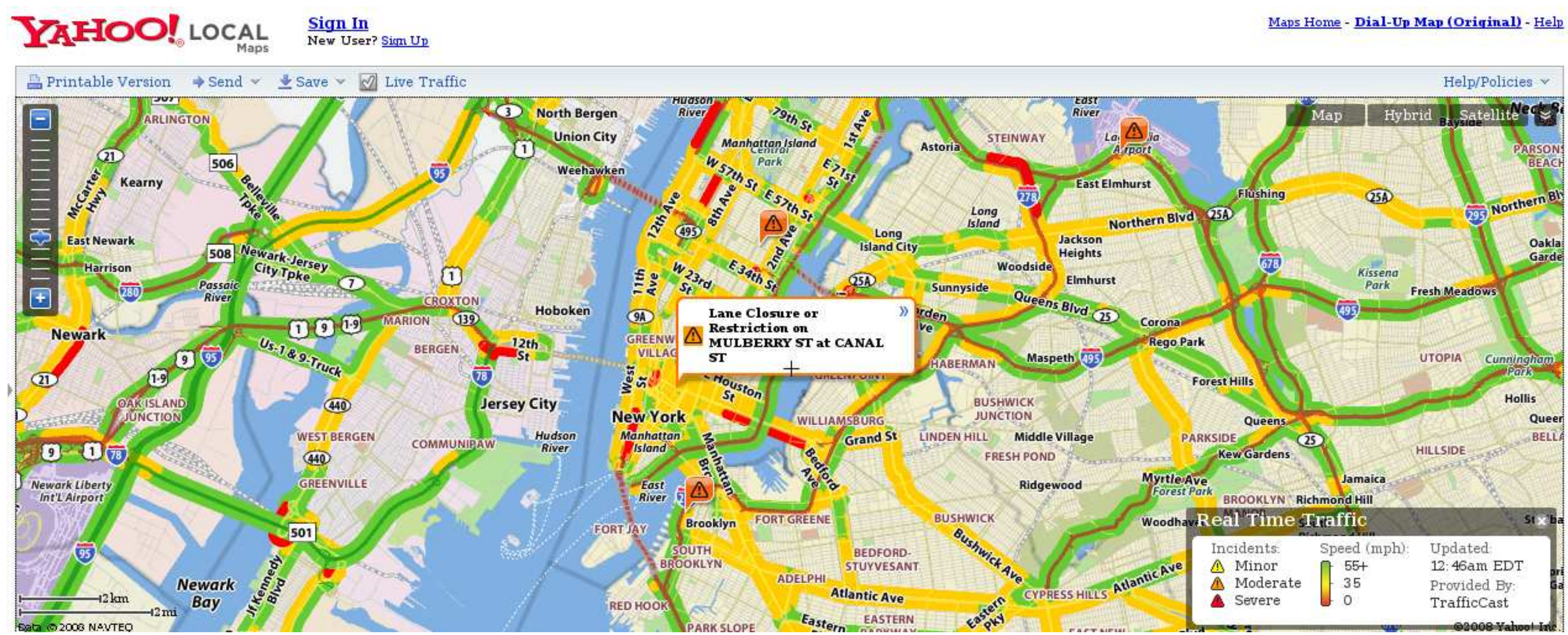
VANETs are

- 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

Preconditions and Assumptions

- 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, ...)

Example: Digital Map



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

- 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

Three Basic Principles

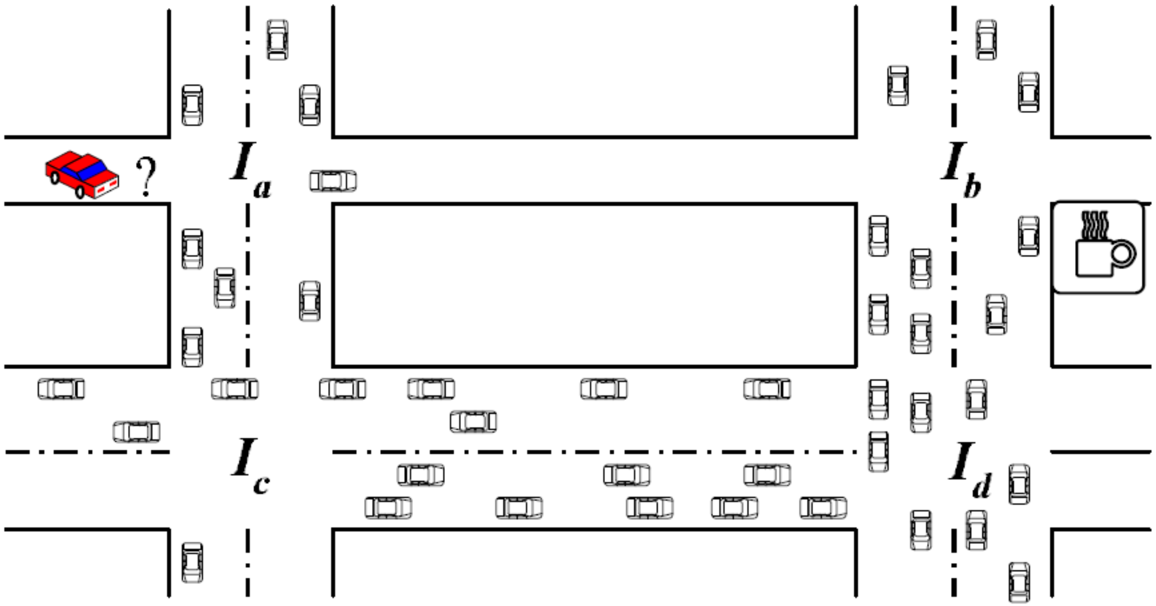
Proposed VADD follows three principles

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

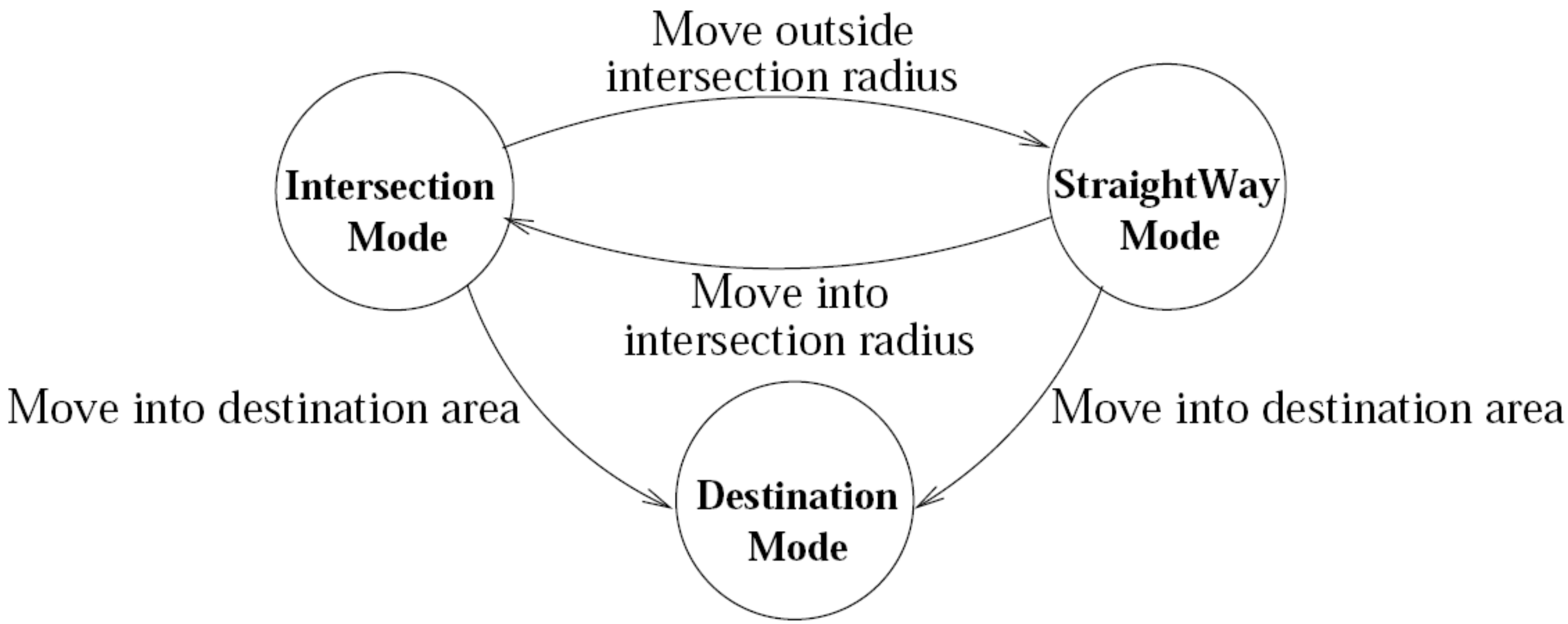
- Idea of carry and forward
- known traffic pattern/road layout (limits vehicle mobility)

Geographical Greedy - not good for sparse VANETs



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

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

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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
- $\longrightarrow$ Use stochastic model instead to select next road

Intersection mode: Which direction to go?

D_{ij} Expected packet delivery delay from I_i to the destination through road r_{ij}

P_{ij} Probability, that packet is forwarded through road r_{ij} at I_i

$N(j)$ Set of neighboring intersections of I_j

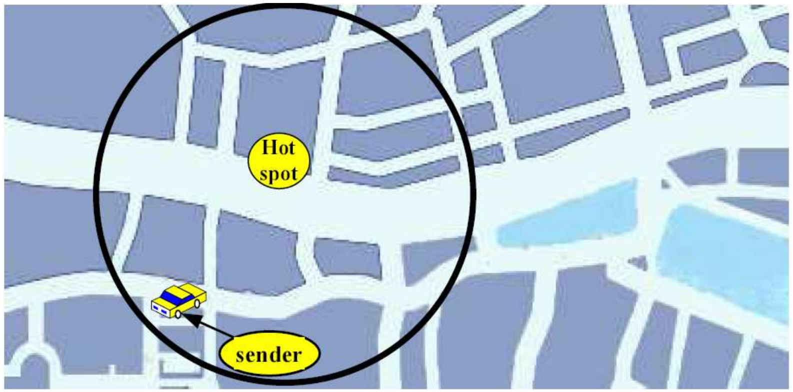
Now compute D_{ij} for each Intersection within boundary

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

- 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

Boundary?

- 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 $D_{ij} \longrightarrow x_{ij}$
  - Subscript ij of d_{ij} and $x_{ij} \longrightarrow$ unique number for each ij
  - Subscript of P_{ij} by its position in the the quations
- n linear equations with n unknowns $x_1, x_2, ..., x_n$

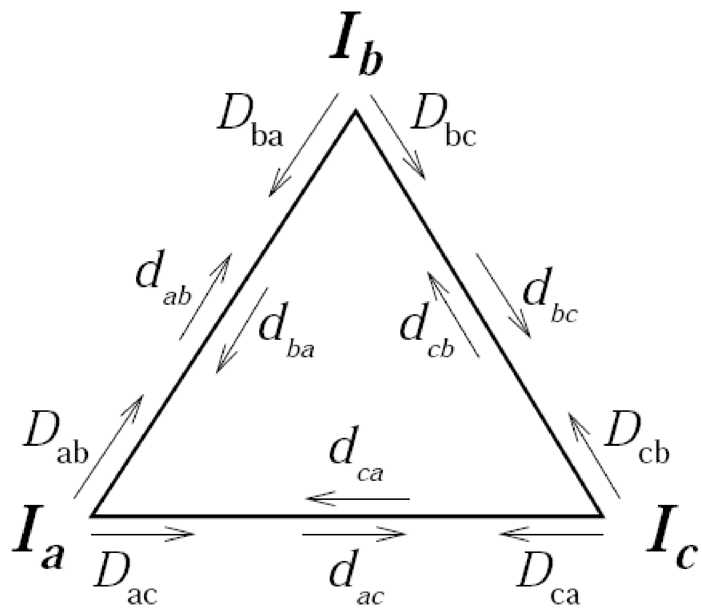
$$(P - E) \cdot X = -D$$

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

$$E = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} D = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{bmatrix}$$

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

Example



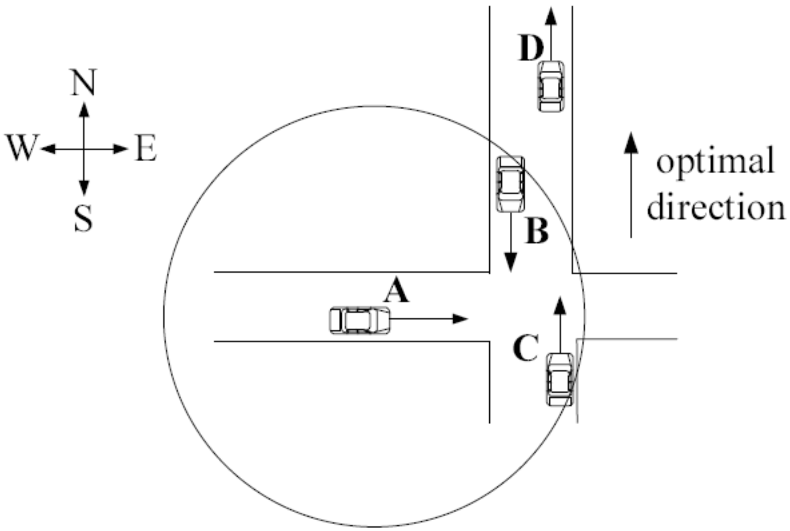
$$
\begin{cases}
D_{ac} = d_{ac} \\
D_{ab} = d_{ab} + P_{ba} \cdot D_{ba} + P_{bc} \cdot D_{bc} \\
D_{ba} = d_{ba} + P_{ab} \cdot D_{ab} + P_{ac} \cdot D_{ac} \\
D_{bc} = d_{bc} \\
D_{cb} = 0 \\
D_{ca} = 0
\end{cases}
$$

The VADD protocols

Intersection Forwarding

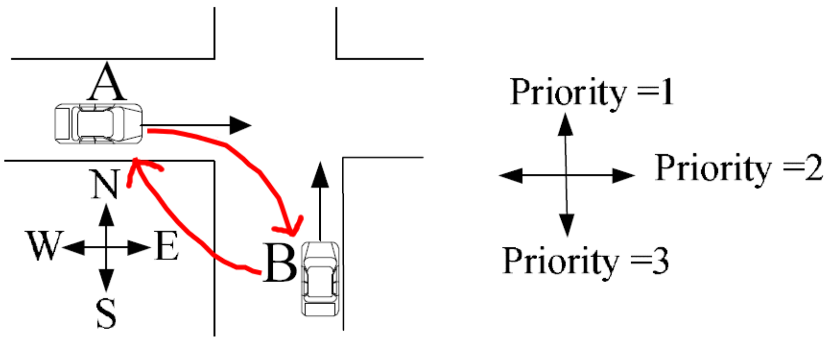
- Now priority list is available
- But: which carrier should we choose?
- Difficult: need to consider mobility and location
- Leads to different intersection protocols:
  - Location First VADD: L-VADD
  - Direction First VADD: D-VADD
  - Hybrid VADD: H-VADD

- Simple solution:
  - Select closest carrier towards preferred direction
  - Moving direction of chosen carrier does not matter
  - Example figure: $A \longrightarrow B$
- Can reduce hops (minimize forwarding distance)
- Possibility of forwarding loops



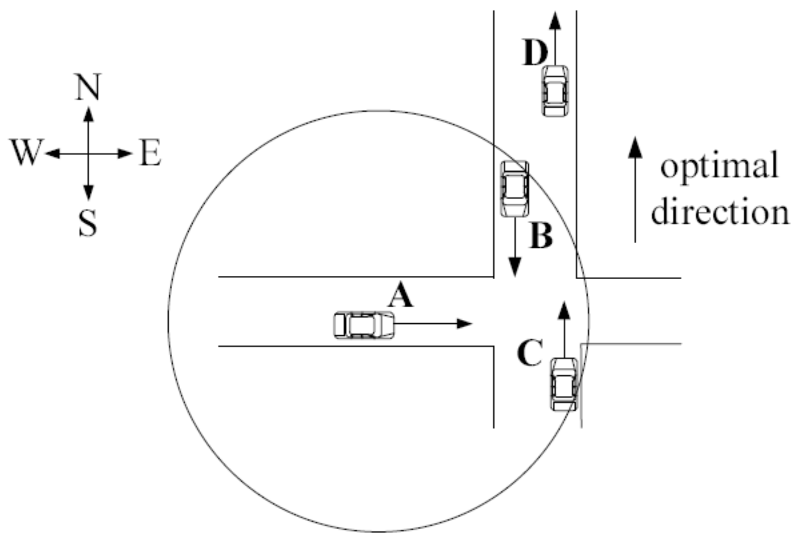
L-VADD: Loops

- Loop-free solution:
  - Check previous hops
  - No forwarding to these hops
  - Could prevent good carriers from beeing selected
- Loops have negative impact on delivery ratio

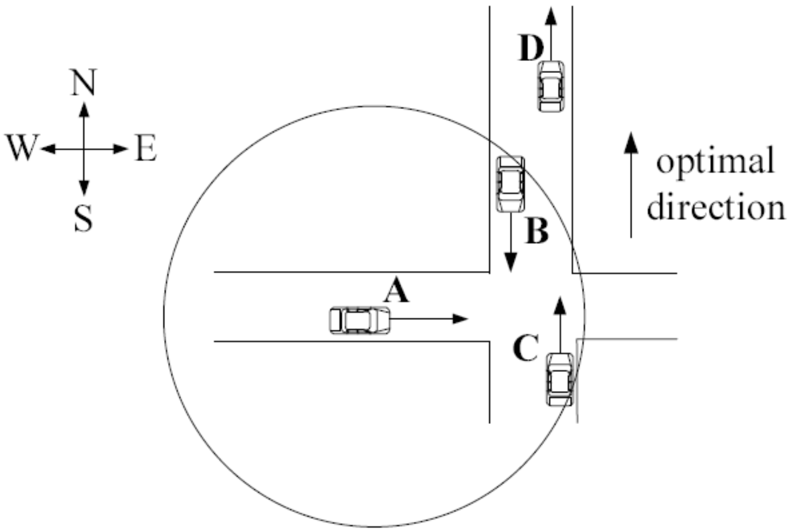


D-VADD: Direction First

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

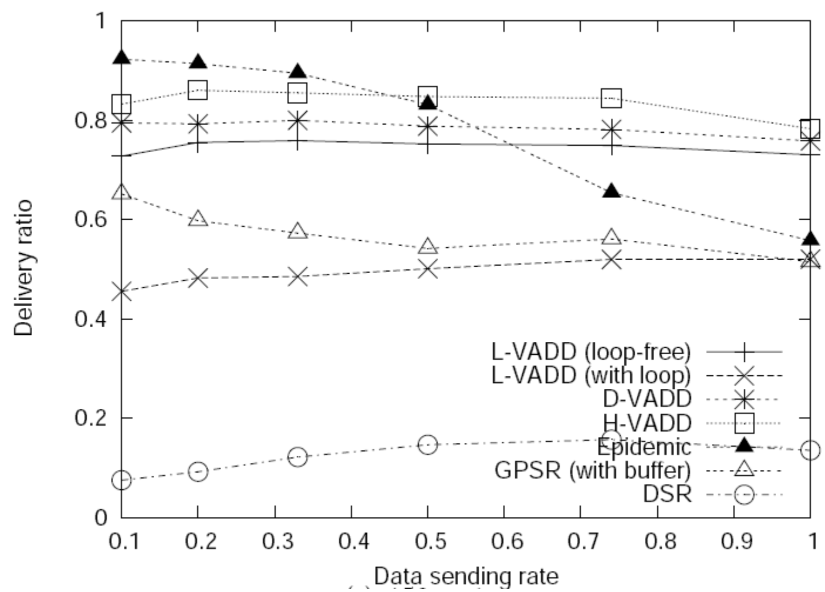


Performance evaluation

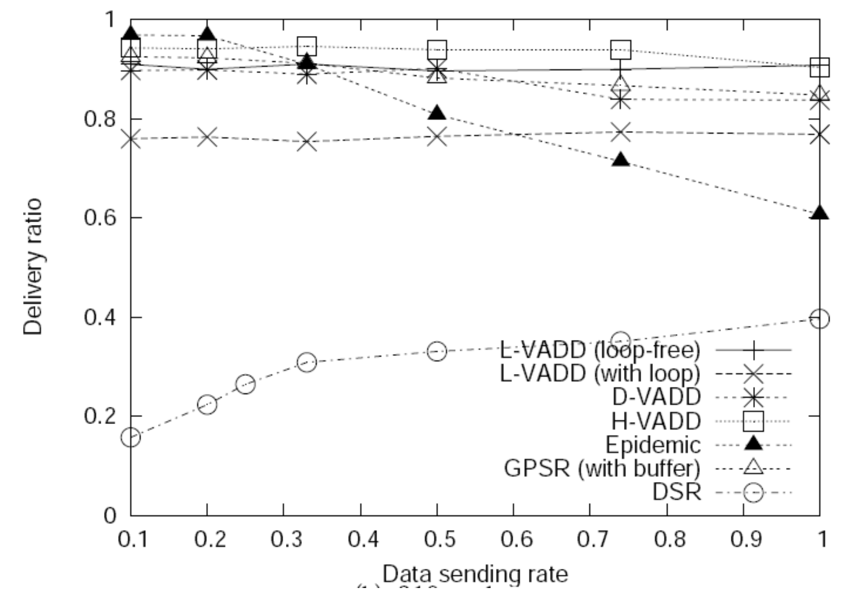
- Metrics
  - Delivery ratio
  - Delay
  - Network traffic
- Compared with
  - GPSR (with buffers*)
  - Epidemic Routing

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

Parameter	**Value**
Simulation area	$4000m \times 3200m$
# of intersections	24
Intersection area radius	200m
Number of vehicles	150, 210
# of packet senders	15
Communication range	200m
Vehicle velocity	15 - 80 miles per hour
CBR rate	0.1 - 1 packet per second
Data packet size	10 B - 4 KB
Vehicle beacon interval	0.5 sec
Packet TTL	128 sec

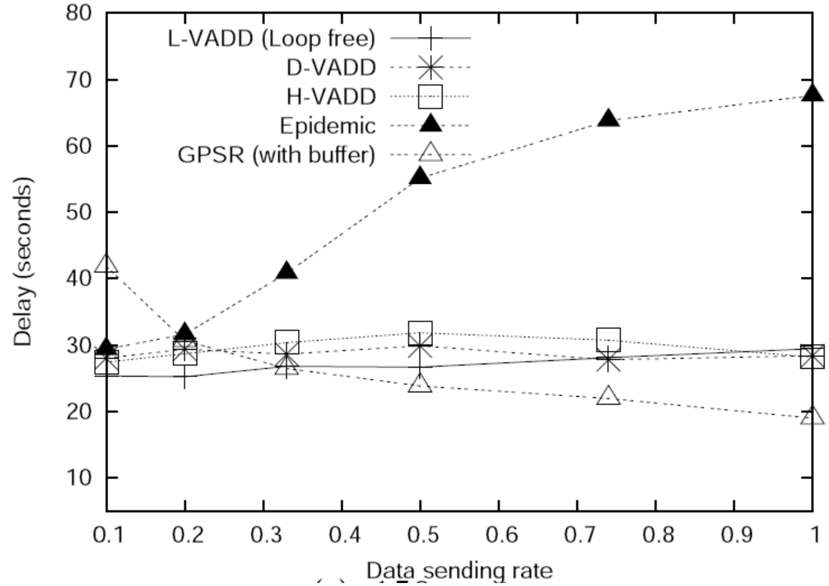


150 nodes

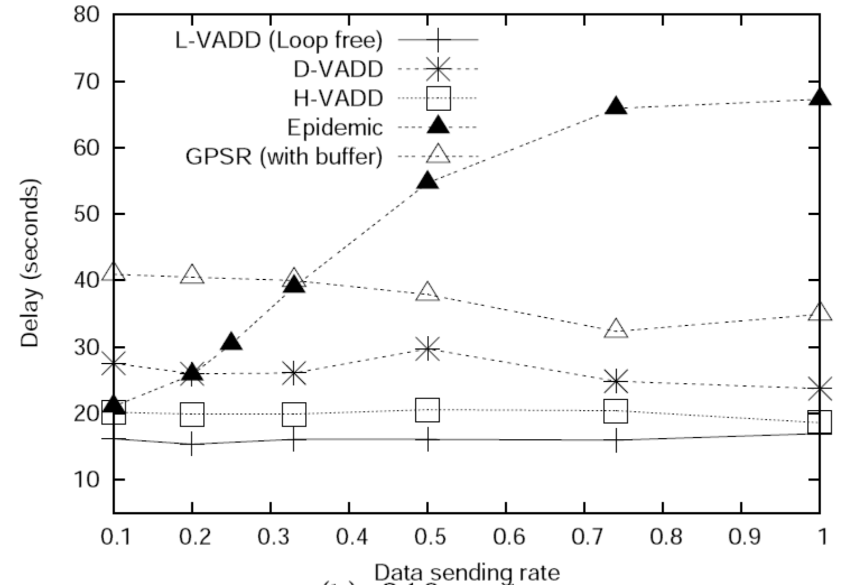


210 nodes

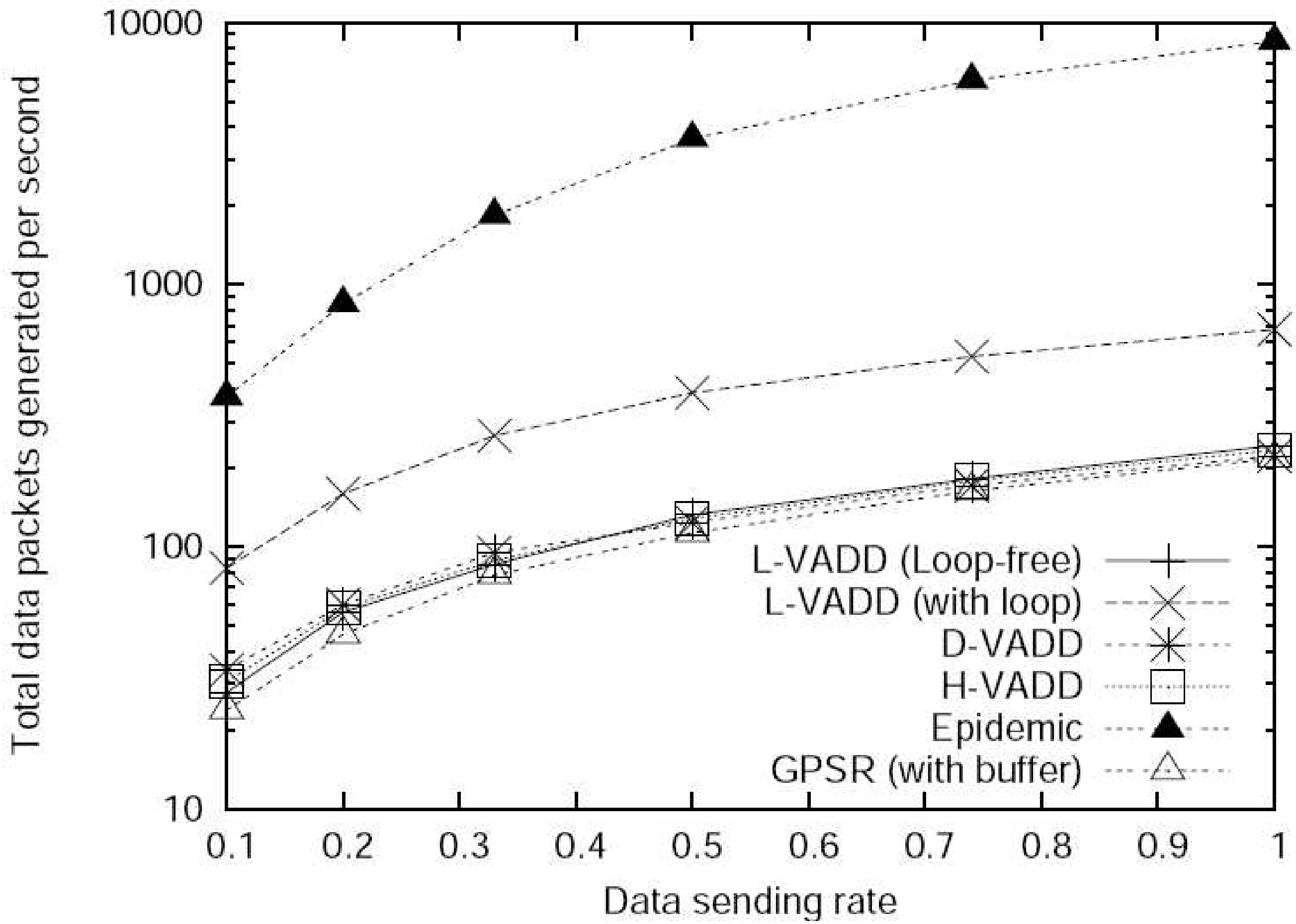
Delay



150 nodes



210 nodes


Total data packets generated per second
10000
1000
100
10
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Data sending rate
L-VADD (Loop-free)
L-VADD (with loop)
D-VADD
H-VADD
Epidemic
GPSR (with buffer)

210 nodes

Summary, Conclusion, Additional Slides

Summary

- VADD uses idea of carry-and-forward
- Make use of predictable vehicle mobility (known street-layout)
- Probabilistic Model and Linear Equiation 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 oocurs 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

References

[1] J. Zhao and G. Cao, ”VADD: Vehicle-assisted Data Delivery in Vehicular Ad Hoc Networks”, IEEE INFOCOM, April 2006