A Multiple Vehicle Sensing Approach for Collision Avoidance in Progressively Deployed Vehicle Network

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Outline

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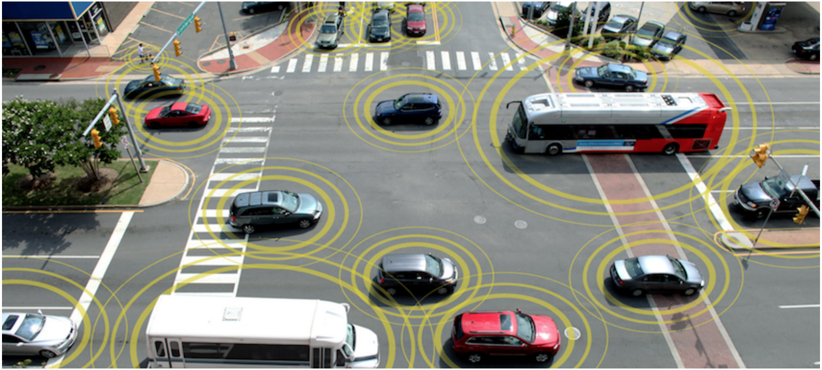
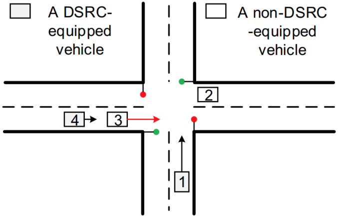
Motivation

- Road Traffic injuries are the eighth leading causes of death,and first leading cause of death for young people 15-29.
- WHO predict, if same pattern continues, in 2030 road traffic death could be the 5th leading death for all ages.
- According to USDOT this wireless technology will reduce unimpaired vehicle crashes by 80%.

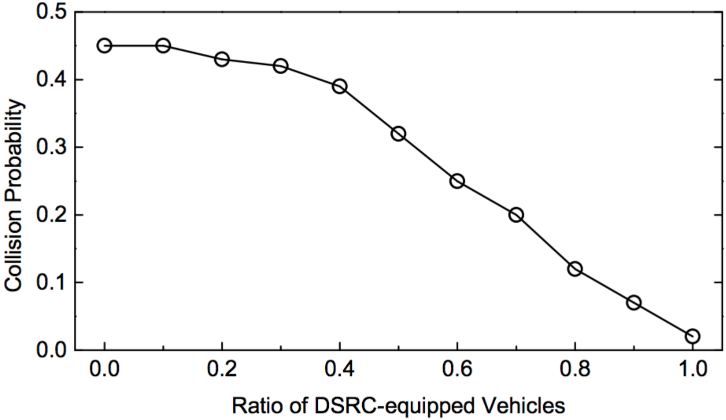


Motivation

- Reduce road traffic injuries utilizing technologies such as Dedicated Short Range Communication(DSRC)
- Bridge the gap where DSRC-equipped vehicles co-exist with non-DSRC-equipped vehicle to benefit from safety applications.
- It will take 5 years to achieve 10% DSRC deployment. The probability DSRC-equipped vehicle will benefit from a safety application is only of 1 %



Motivation



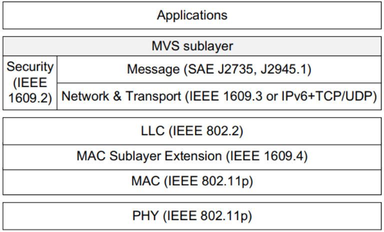
0.5
0.4
0.3
0.2
0.1
0.0
Collision Probability
0.0
0.2
0.4
0.6
0.8
1.0
Ratio of DSRC-equipped Vehicles

Approach

- Multi-Vehicle Sensing (MVS) design to improve the collision avoidance effectiveness with partial DSRC deployment. Make each DSRC-equipped vehicle sense adjacent vehicle and broadcast to other DSRC-equipped vehicles.
- Use cameras and/or on-board radars to sense kinematic information of adjacent vehicles. To account for sensing inaccuracy, use multiple sensing results about the same vehicle.
- MVS uses two key components, *selective broadcasting* and *cooperative estimation.* To account for sensing inaccuracy, use multiple sensing results about the same vehicle.

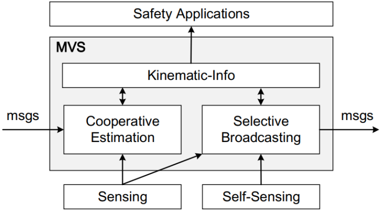
Background of DSRC

- Each DSRC-equipped vehicle broadcasts its Kinematic information to other vehicles periodically. Then based on received infromation about nearby vehicles it can predict possible collisions and *trigger alert* to the driver



Overview

- MVS design propsed three main design goals.
  - MVS should be decentralized.
  - MVS design should be compatible to current layered design of DSRC.
  - kinematic status estimation of a non-DSRC-equipped vehicle should be accurate as possible
- Use Selective broadcasting and cooperative estimation



Design

Selective Broadcasting

- straightforward design: Each DSRC-equipped vehicle senses adjacent vehicles and broadcast the sensed information.
  - Simple and easy to implement
  - Poor channel efficiency
  - Suffer from message delivery reliability

- Make each Dsrc-equipped Vehicle forward the received MVS message.
  - Improve channel efficiency
  - Improve message delivery reliability

Design...Continued

Notation: Three kinds of information about the kinematic state of a non-DSRC-equipped vehicles.

- $dm\langle v_i, t_j \rangle$ denotes direct Measurement.
- $im\langle v_i, t_j \rangle$ denotes indirect Measurement.
- $m\langle v_i, t_j \rangle$ denotes Generic Notation.
- $e\langle v_i, (t_{j1}, t_{j1}, ...t_j) \rangle = e\langle v_i, T_j \rangle$ to denote an estimate

Selective Broadcasting Algorithm

Algorithm 1 Measurements/estimates selection

Input: All received/sensed measurements/estimates (MEs) during the past time window, $sig(v_i)$ for each v_i, the maximum number of output MEs M

Output: A set B of measurements/estimates to broadcast

procedure SELECTION
    Let B be an empty set of MEs
    Let $ME1$, $ME2$ be two empty lists of MEs
    for each known non-DSRC-equipped vehicle v_i **do**
        if there are more than one MEs about v_i **then**
            $e\langle v_i, T_j\rangle$ = Estimate(all MEs about v_i)
        else
            keep the only ME about v_i
        Let $ME(v_i)$ be the measurement/estimate of v_i
        if there exists $dm\langle v_i, t_j\rangle$ **then**
            $ME1$.append($ME(v_i)$)
        else
            $ME2$.append($ME(v_i)$)
    sort $ME1$ and $ME2$ based on $sig(v_i)$, largest first
    while $|B| < M$ and $ME1 \neq \emptyset$ **do**
        $B = B \cup \{$first ME in $ME1\}$
        remove the first ME in $ME1$
    while $|B| < M$ and $ME2 \neq \emptyset$ **do**
        $B = B \cup \{$first ME in $ME2\}$
        remove the first ME in $ME2$

Design

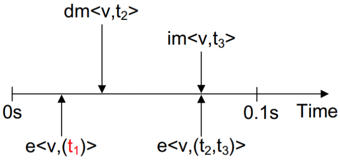
Collaborative Estimation

- *Goal*:
  - To estimate the kinematic states of Non-DSRC-equipped vehicles
  - To select a number of independent measurement/estimates with maximum unique measurements
- Kalman Filter Modeling: $z_t = H \cdot x_t + v_t$

$$H = \begin{cases} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} & \text{when } d_m \text{ or } m_i \text{ is available} \\ \\ \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} & \text{otherwise} \end{cases}$$

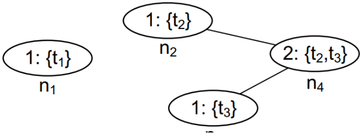
Example

Measurement and estimates of a vehicle v



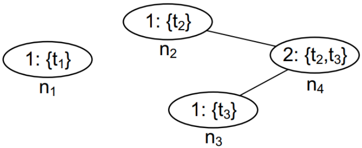
- Measurement at t2 and t3 used twice ...incorrect estimation
- where there are a large number of measurement/estimates calculating all could be time consuming

proposed solution: measurements/estimates can be represented by timestamps ie,. $\{t_1\}, \{t_2\}, \{t_3\}, \{t_2, t_3\}$



Example...continued

Goal: select a number of vertices which do not have any links connecting them and have the maximum total vertex value



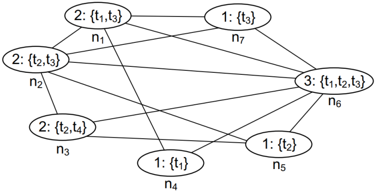
*Catch: A *maximum -weight independent set (MWIS) problem is NP-hard*

***claim:** The maximum total vertex value represents the number of direct measurement about vehicle conducted by different DSRC-equipped vehicles?

$\{n_1, n_2, n_3\} = 1 + 1 + 1 = 3$ or $\{n_1, n_4\} = 1 + 2 = 4$

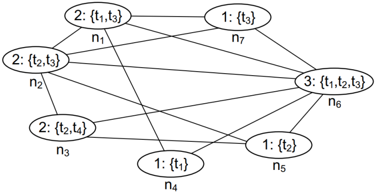
Example 2

Goal: select a number of vertices which do not have any links connecting them and have the maximum total vertex value

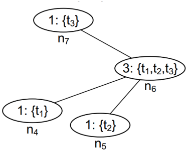


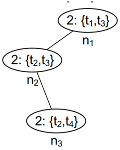
- There are 4 timestamps $(t_1, t_2, t_3 t_4)$
- find solution with total vertex value of 4...**NO**
- Try solution structure $\{1, 3\}$ and $\{2, 2\}$ ... **Yes**

Example 2...continued

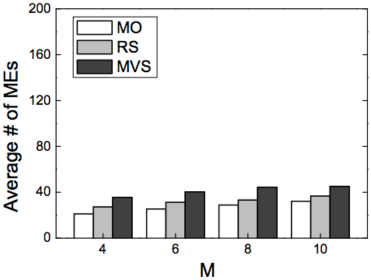


Two subgraphs of two solution structures.

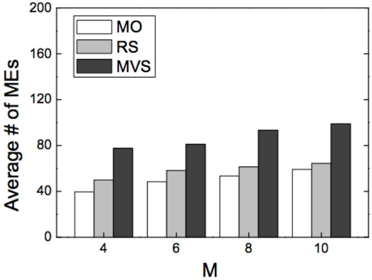




Evaluation



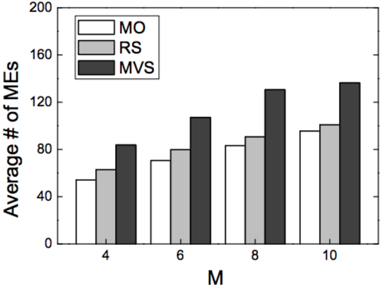
(a) 10%



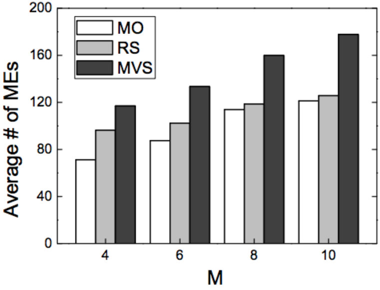
(b) 20%

When there are more DSRC-equipped vehicles, the number of different received MEs increases

Evaluation



(c) 30%



(d) 40%

When there are more DSRC-equipped vehicles, the number of different received MEs increases

Evaluation of Cooperative Estimation

Comparison with randomly selecting measurement/estimates Vs collaborative estimation (selecting independent measurement with maximum unique measurements).

Method	Average # of reused measurements				Average # of selected MEs			
	10%	20%	30%	40%	10%	20%	30%	40%
RS	0.2	1.2	4.6	9.4	1.4	3.5	7.2	13.2
MVS	0	0	0	0	1.3	1.7	3.1	4.6

1. It will select multiple dependent measurement/estimates and reuse some....Inaccurate estimation
2. Number of selected measurement/estimate maybe much larger....computational overhead of the estimation

Collision Avoidance Effectiveness

When using MVS the collision probability drops significantly when the number of DSRC-equipped vehicle increase.

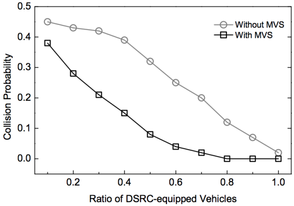


Figure: Dense

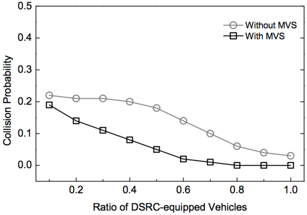


Figure: sparse

Limitation

- propose a method to do vehicle matching using $dm\langle v_i, t_j\rangle$. It does not describe what searching algorithm would be used for such matching.
- propose a method to does not account for latency in communication
- Cooperative Estimation assumes the case where $dm\langle v_i, t_j\rangle$ is lost and $e\langle v_i, T_j\rangle$. is received however it is not clear from the paper how portion of message could be lost. Moreover paper does not assume case where message is lost completely

Conclusions

Addressed topics:

1. Traffic injuries are leading causes of death and DSRC is a promising solution to reduce number of accidents
2. DSRC deployment is slow, hence use MVS during partial deployment of DSRC.
3. design of MVS:
   - Selective broadcasting
   - cooperative Estimation
4. Evaluation and analysis shows using MVS is able to reduce collision probability by $\approx 60\%$ when there are 40% deployment.

Thank you for your attention!

QUESTIONS?