Information Dissemination Dynamics through Vehicle-to-Vehicle Communication over Transportation Networks.

Alobeidyeen, Ala, Ph.D. student, University of Florida
Du, Lili  Associate Professor, University of Florida

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Background and Motivation

- **Vehicle to Vehicle (V2V)**
  - DSRC protocol; Hundreds of meters (<1k)
  - Improve traffic safety and **mobility**

- **Understanding Information Availability**
  - How fast information spreads?
  - How traffic flow affects

- **Challenges:**
  - Communication range, noise, etc.
  - High traffic mobility and dynamics.
  - Information lifetime.

(V2V) communications

Information Dissemination via V2V
Research Objectives

- Develop a discrete mathematical simulation model to track the information spreading dynamics over a transportation network (road segments, intersections).

- Capture the information coverage dynamics over the transportation network.

- Explore the correlation between information spreading dynamics and traffic congestion.
Information Front and Wave on Network

- On road segments:
  Follow intermittent transmission pattern
  Form the information wave with two boundaries (fronts/tails).

- Intersection:
  Front disseminates to different directions

- Network
  Fronts and tails forms the spreading boundary of the wave.
Methodology: IT-CTM for Road Segment

Information-Traffic Coupled Cell Transmission Model (IT-CTM)

- IT-CTM cell with $\Delta x$, covering several intermittent patterns.

- Each cell keeps three pieces of information including: passing front, tail and traffic volume: $\{n_j(t), f_j(t), \tau_j(t)\}$

- Inner-cell front/tail propagation and delay: forward, backward or stay in a cell (depends on intermittent transmission state).

- Inter-cell front/tail propagation: forward, backward or stay (depends on the states of two adjacent cells).


Methodology: Information Flow Network Model for arterial intersection (IFNM-a)

- Many potential routes
- Hard to enumerate

- Depends on
  - The existing flow at each arm,
  - Various vehicle mobility,
  - Combinations of wireless and ferry transmissions.

- IFNM-a for Arterial Intersection

- Network components
  - Nodes
    - IT-CTM cells adjacent to intersection
  - Links (0-1 state with delay)
    - Y: Wireless transmission and delay
    - X: Ferry transmission and delay

- Information front will always spread by taking the fastest/shortest path.
Methodology: Information Flow Network Model at Highway-Ramp Intersection (IFNM-r)

- The Front may take many routes
  - Mixed transmissions:
    - Y: wireless transmission.
    - X: ferry transmission.
    - Z: intra-cell transmission between IT-CTM cells at the connection of highway and ramp.

- IFNM-r for a Highway-Ramp Intersection

- Scope of the network

\[ l_1 = \frac{r_b}{\sin \theta}, \quad l_2 = \frac{r_b}{\sin \theta}, \quad l_3 = r_b \]
Methodology: IFNM-CTM for Network Spreading

- Information flow network model Coupled with IT-CTM (IFNM-CTM)
  - IFNM-a tracks the information spreading dynamics at arterials intersection (un/signalized)
  - IFNM-r tracks the information spreading dynamics at various intersection (highway-ramp)
  - IFNM-CTM integrate the IFNM-a, IFNM-r and the IT-CTM; tracks the information spreading dynamics over a network

A small Network example

IFNM-a

IFNM-r

IFNM-CTM

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Methodology: Coverage dynamics (Machine learning)

- **Information coverage Matrix**
  - Present road network by IT-CTM cells.
  - Coverage Matrices: Front (F) tail (T)
    - 1: front/tail passed cell j
    - 0: Otherwise

- **Searching connected clusters**
  - Track cell clusters by depth first search (DFS).
  - Determine the numbers of clusters.
  - Size of each cluster (how many cells inside each cluster).

\[
F = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & \cdots & \cdots & 0 \\
0 & 1 & 0 & 0 & 0 & \cdots & \cdots & 0 \\
1 & 1 & 1 & 1 & \cdots & \cdots & 0 \\
0 & 1 & 1 & 0 & \cdots & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \ddots & \ddots & \vdots \\
1 & 1 & 1 & 1 & \cdots & \cdots & 0 \\
\end{bmatrix}
\]

Front coverage matrix
Results: Spreading Dynamics

- **Testbed**: Sioux Falls city network
- 24 intersections; 38 link

- **VISSIM** simulation for traffic data
  45 mins; 13 mins warm up

- The avg MAE for the locations of 15 fronts < 6% for 132 runs.
Information coverage obtained from the simulation and the mathematical model of IFNM-CTM are very close at each individual time stamp.

The average MAE is 4.72% with a very small standard deviation equal to 0.01152.
Results: Congestion and Information Coverage Correlation

- The **number** and **size** of the informed clusters $C_F(t)$ and the congested cells $C_G(t)$ show high correlation.

- The similarity/consistence of the **cells** in informed clusters $C_F(t)$ and the congested cells $C_G(t)$ is 80% on the average.

- **IFNM-CTM** approach to capture the Congestion and Information Spreading Correlation over time in a roadway network.

The number (a) and size (b) of clusters under congestion $C_G(t)$ and passed by information front $C_F(t)$
Conclusions & Summary

- Understanding information spreading dynamics in transportation network is essential to sustain the mobility application of V2V technology.
- Our approach IFNM-CTM (IFNM-a, IFNM-r, IT-CTM) can capture information spreading over transportation network.
- The accuracy of the proposed approach is satisfied by < 6% MAE and < 5% MAE for tracking network information front location and coverage dynamics.
- The strong correlation between traffic congestion and information spreading coverage shows a promising index to identify congestion over a network.

Ala and Du @ University of Florida
THANK YOU!

Q&A

lilidu@ufl.edu University of Florida

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