An Investigation into the Performance Evaluation of Connected Vehicle Applications: From Real-World Experiment to Parallel Simulation Paradigm

Presented by

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Research Goals

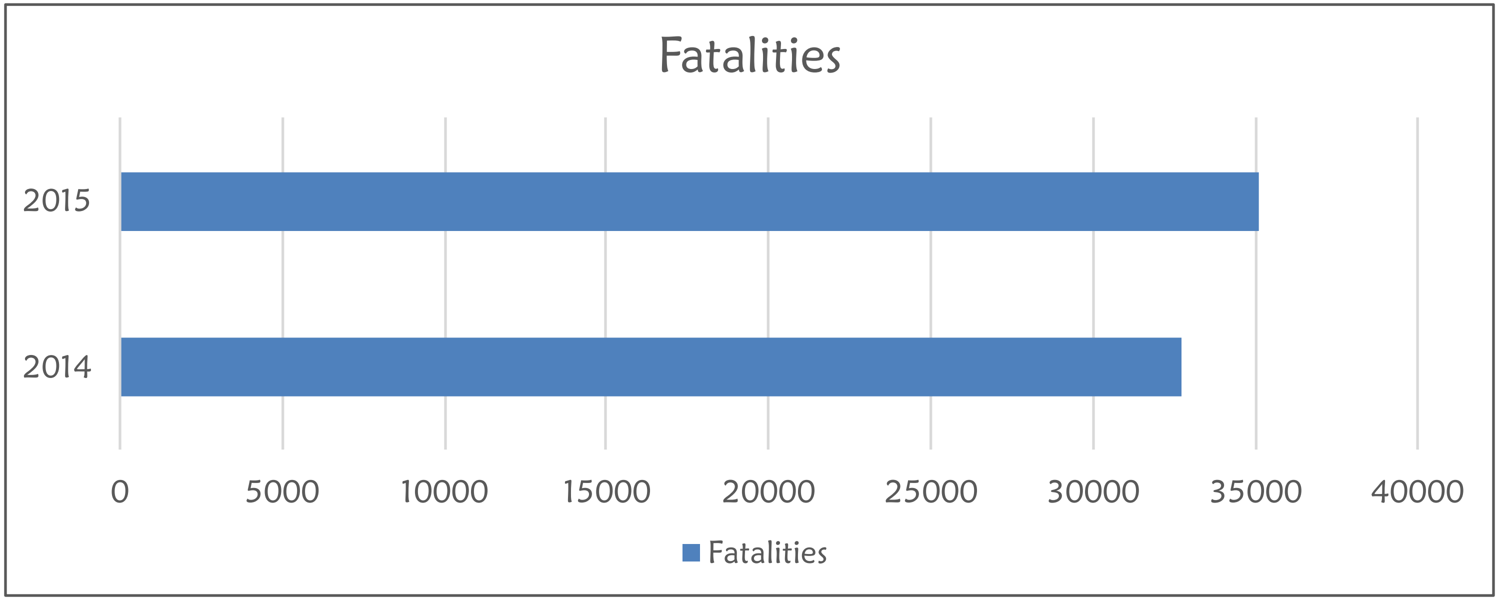
- Four major objectives:
  1. Implementation of a connected-vehicle (CV) Application.
  2. Devise of a Parallel Simulation Framework.
  3. Transportation Network Partitioning.
  4. Investigation of the inter-simulator communication overhead.

Research Goal 1

Implementation of a CV Application (freeway merge assistance system)

Motivation

1st half of 2016 is 10.4% more than 1st half of 2015



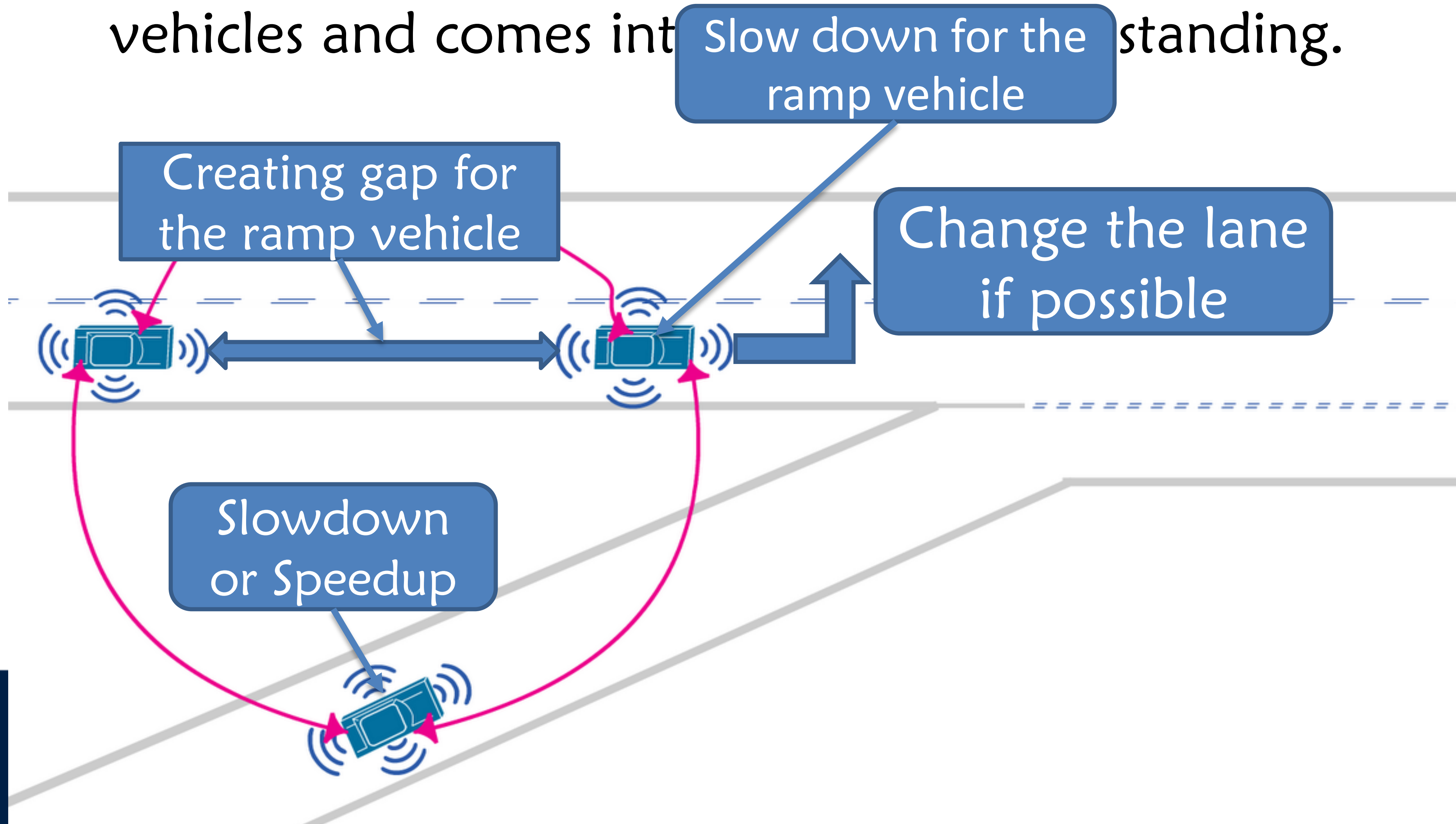
Motivation (Cont'd)

About **20-30%** of truck accidents happens due to **merge conflicts from ramps to freeways** (Janson et al.).

Source: Google image

Merge Assistance System

A vehicle on the ramp communicates with the freeway vehicles and comes int standing.



Merge Assistance System

Can be

- Centralized
- Decentralized
- For autonomous vehicle

Scope of this study

Decentralized Algorithms

- Wang et. al. describes a **proactive algorithm** and **suggests speed** for all vehicles.
- Park et. al. calculates **safe gap** using speed and provides both **lane-changing & merging** advisory information.
- Hayat et. al describes the **driver compliance** to the advisory messages.

Common Idea

Almost all the **merge control algorithms** are based on

- Position,
- Speed,
- Acceleration, and
- Time to reach the merging point.

Communication Technologies

Researchers used different communication techniques for the **merge control algorithms**

- Infrastructure support such as **coded magnets** or **transponders** (Lu et al.).
- **Internet** based (Wang et al.).
- **Theoretical DSRC** with simulation tools (Park et al., Hayat et al., and Hall et al.).

Challenges & Issues

- Most researchers used **simulation tools** to evaluate their algorithms.
- **No one used actual DSRC devices.**
- Thus, they overlook some **unanticipated challenges.**

Challenges & Issues (Cont'd)

- **Lane detection**
  - The merge assistance system should consider only the **conflicting vehicles** on the rightmost lane.
  - The system should ignore **non-conflicting vehicles**.

- **Advisory start time**
  - Each driver should get adequate time to think about the advisory messages.
  - **Not too late**
  - **Not too early**

Challenges & Issues (Cont'd)

- **Dist**

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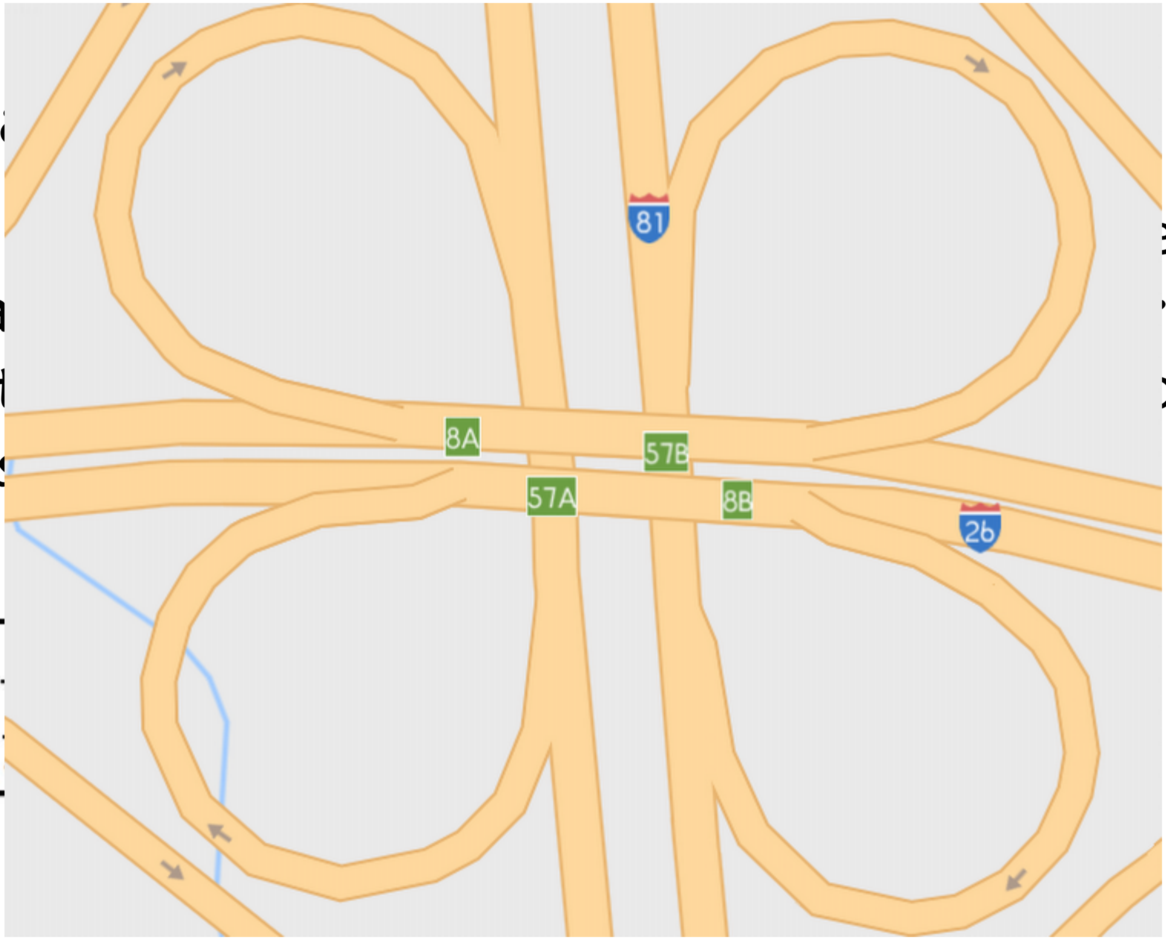
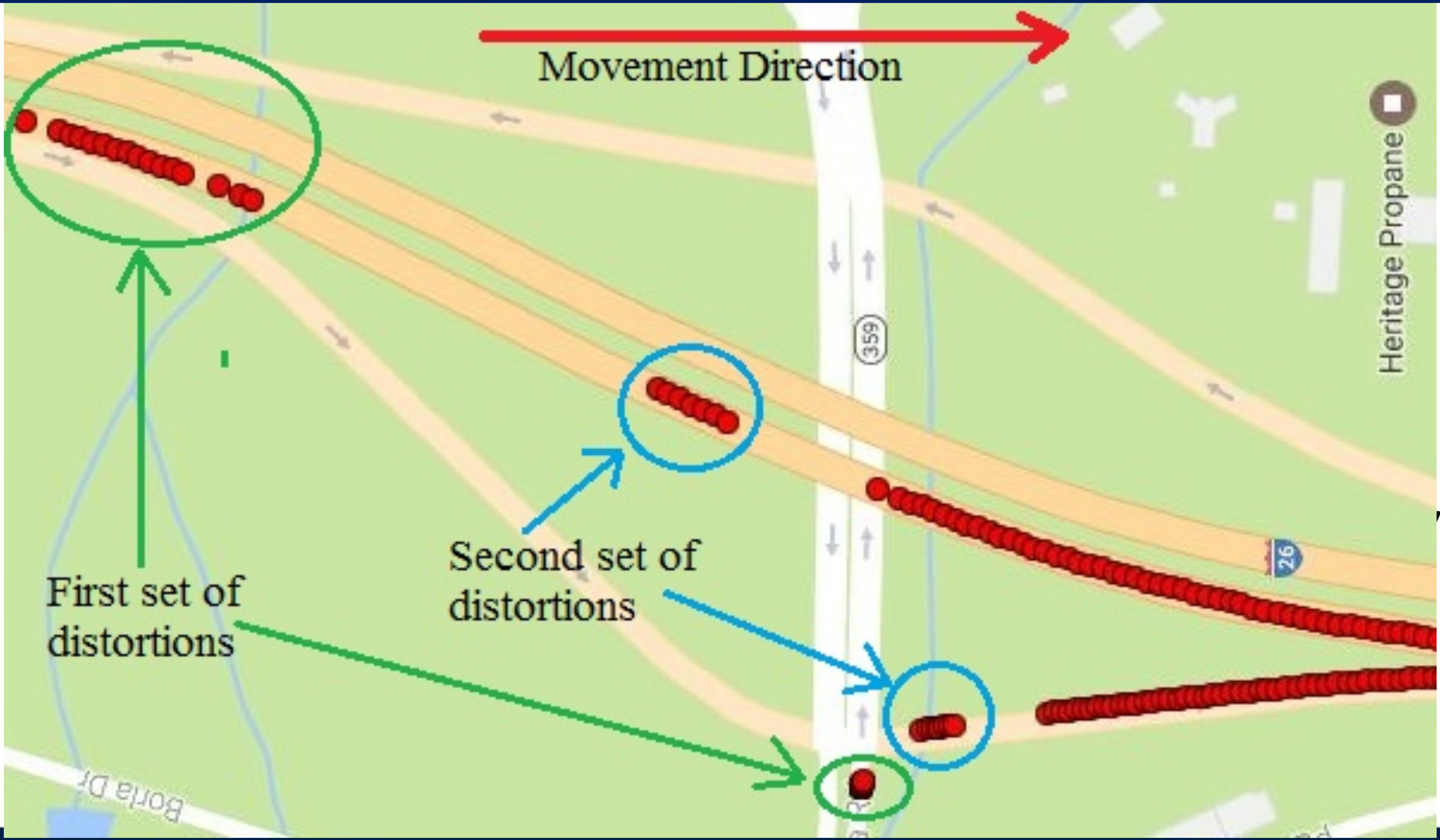


Challenges & Issues (Cont’d)



Challenges & Issues (Cont'd)

- Driver compliance
  - Drivers may or may not comply with the advisory messages.
  - **40%** drivers do not comply when the **gap sizes are small** (Hayat et al.).
  - **32%** drivers comply lane changing advisories when they can move to **higher speed lanes** (Hayat et al.).

Advisory Model

- **The algorithm executes within the ramp vehicle**
- **The basic idea**
  1. The ramp vehicle keeps track of vehicular **trajectories for all the conflicting vehicles** on the freeway.
  2. Determination of the **timing information.**
  3. Broadcast of **control** messages.
  4. Acknowledge the control messages using **synchronization** messages.
  5. Generation of **advisory** messages.
  6. Display of the advisory messages in the smartphone application.

Assumptions

- **We assumed the following criteria:**

1. The assistance system is for only the connected-vehicle environment.

2. DSRC communication delay is negligible (order of milliseconds).

3. Computation cost is negligible (order of milliseconds).

4. The entrance ramps are not circular and are not significantly bent.

Preliminary Data Collection

- We collected preliminary data to develop our advisory model.
- BSM payload fields:

MAC	TS	Lat	Lon	Alt	S	Lat Dir	Lon Dir

MAC	=	Address of the OBU
TS	=	Timestamp
Lat	=	Latitude
Lon	=	Longitude
Alt	=	Altitude
S	=	Speed
Lat Dir	=	Latitude Direction
Lon Dir	=	Longitude Direction

Location 1

- I-26 (Exit 27, both West and East Bound)

Location 2

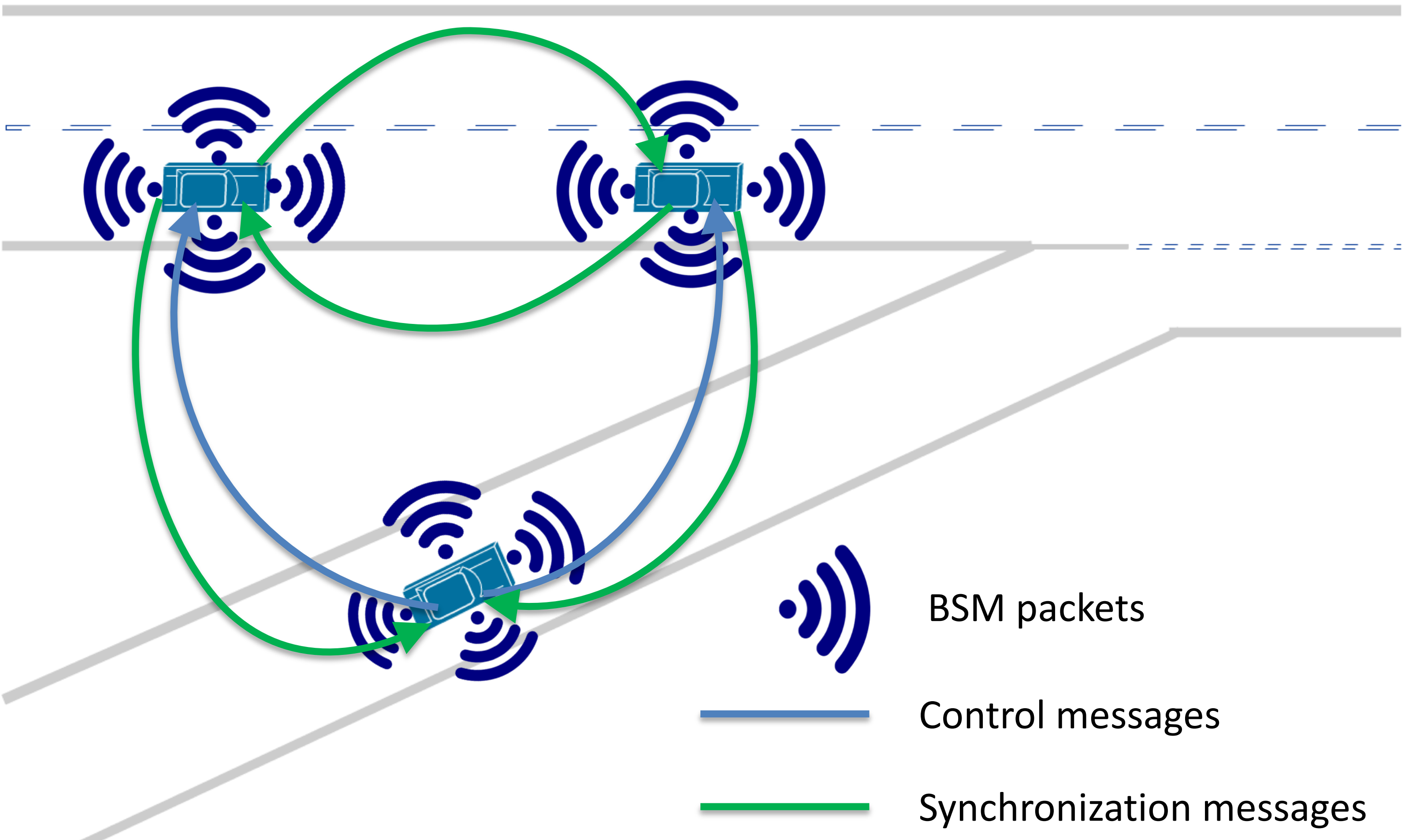
- US 321 (The first entrance ramp where University Parkway ends)

Communication Protocol

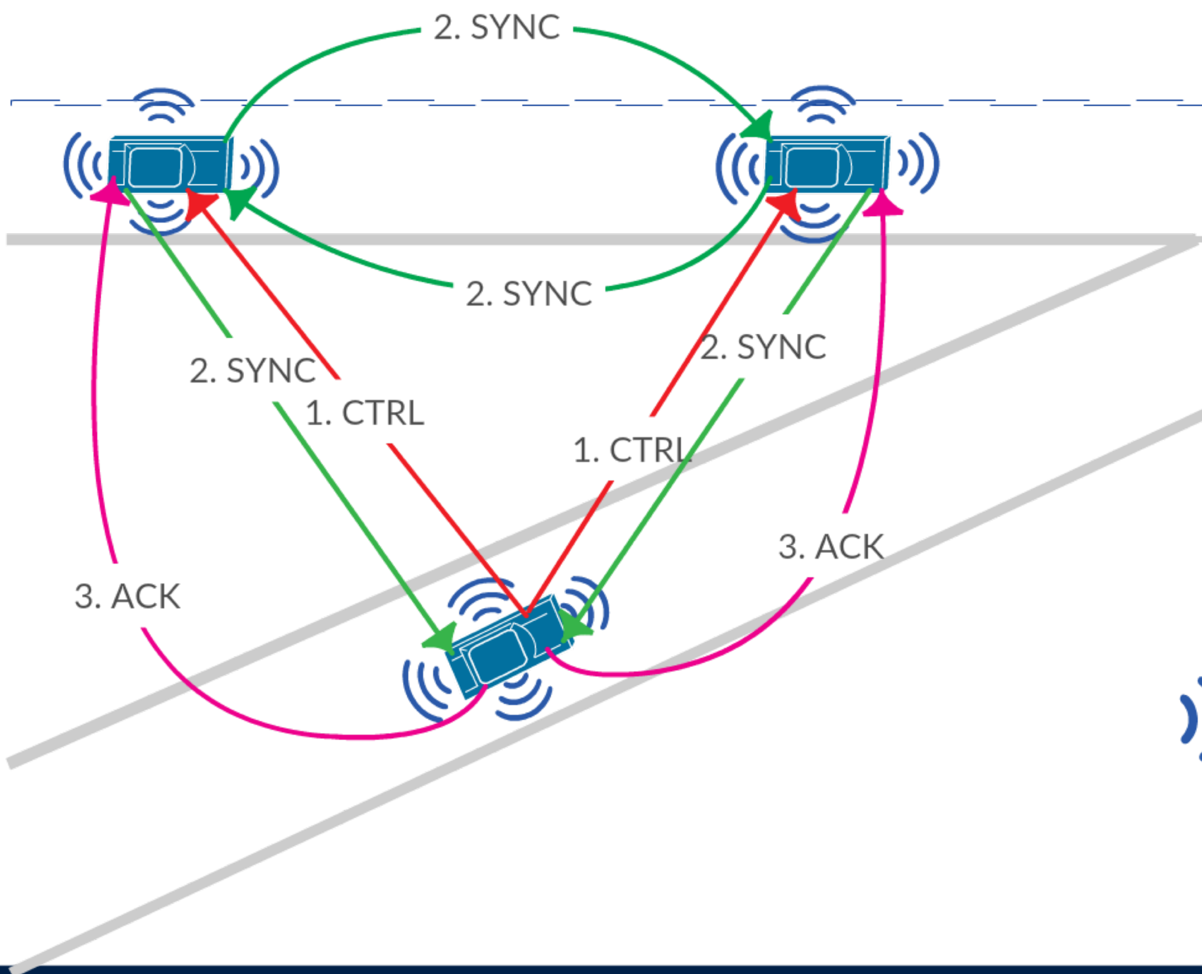
- Single hop communication protocol for
  - Transmitting BSM packets.
  - Transmitting control messages.
  - Transmitting synchronization messages.

- Bluetooth communication for
  - Displaying advisory message in an Android devices.

Communication Protocol (Cont'd)



Communication Protocol (Cont'd)



CTRL = Control Message
SYNC = Synchronization Message

Each vehicle is transmitting
BSM packets all the time

CTRL & SYNC Fields

- Fields of a CTRL message:

MAC	TTC	TDM

MAC	=	Address of the OBU
TTC	=	Time to reach the crash/merging point
TDM	=	Timestamp of making advisory decisions

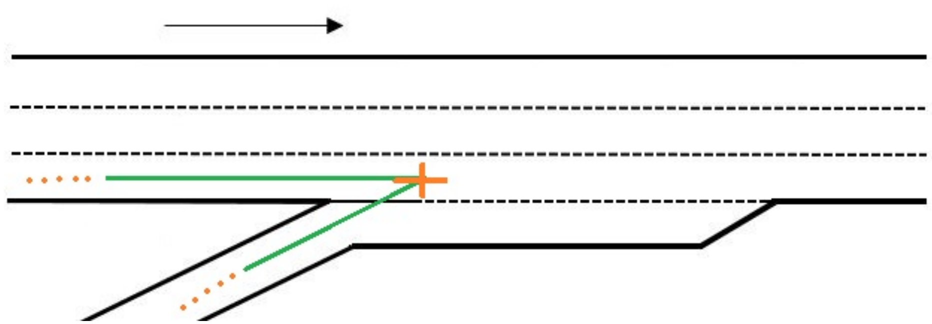
- Fields of a SYNC message:

IER	RT	IDM	TTC

IER	=	Is the vehicle on the entrance ramp?
RT	=	Amount of time spent by a vehicle on the ramp
IDM	=	Is the advisory decision made?
TTC	=	Time to reach the crash/merging point

Merging Prediction Model

1. Approximation of the merging point.
2. Calculation of the average acceleration of the ramp vehicle and average speed of the freeway vehicle.
3. Calculation of the distance between a vehicle and the merging point.
4. Calculation of the time required to reach the merging point using kinematics equations.



Merging Prediction Model (Cont'd)

1. Calculation of a bearing:

$$\theta = \text{atan2}(\sin\Delta\lambda\cos\phi_2, (\cos\phi_1\sin\phi_2 - \sin\phi_1\cos\phi_2\cos\Delta\lambda)) \quad (1)$$

where ϕ_1, λ_1 is the starting point, ϕ_2, λ_2 the end point and $\Delta\lambda$ is the difference in longitude.

2. Predicting the merging point:

$$\delta_{12} = 2\arcsin(\sqrt{(\sin^2(\frac{\Delta\phi}{2}) + \cos\phi_1\cos\phi_2\sin^2(\frac{\Delta\lambda}{2}))})$$
$$\theta_a = \arccos(\sin\phi_2 - \frac{\sin\phi_1\cos\delta_{12}}{\sin\delta_{12}\cos\phi_1})$$
$$\theta_b = \arccos(\sin\phi_1 - \frac{\sin\phi_2\cos\delta_{12}}{\sin\delta_{12}\cos\phi_2})$$

if $\sin(\lambda_2 - \lambda_1) > 0$

$$\theta_{12} = \theta_a$$
$$\theta_{21} = 2\pi - \theta_b$$

else

$$\theta_{12} = 2\pi - \theta_a$$
$$\theta_{21} = \theta_b$$

$$\alpha_1 = (\theta_{13} - \theta_{12} + \pi)\%2\pi - \pi$$
$$\alpha_2 = (\theta_{21} - \theta_{23} + \pi)\%2\pi - \pi$$
$$\alpha_3 = \arccos(-\cos\alpha_1\cos\alpha_2 + \sin\alpha_1\sin\alpha_2\cos\delta_{12})$$
$$\delta_{13} = \text{atan2}(\sin\delta_{12}\sin\alpha_1\sin\alpha_2, \cos\alpha_2 + \cos\alpha_1\cos\alpha_3)$$
$$\phi_3 = \arcsin(\sin\phi_1\cos\delta_{13} + \cos\phi_1\sin\delta_{13}\cos\theta_{13})$$
$$\Delta\lambda_{13} = \text{atan2}(\sin\theta_{13}\sin\delta_{13}\cos\phi_1, \cos\delta_{13} - \sin\phi_1\sin\phi_3)$$
$$\lambda_3 = (\lambda_1 + \Delta\lambda_{13} + \pi)\%2\pi - \pi$$

3. Calculation of a linear distance:

Haversine Formula

$$a = \sin^2(\frac{\Delta\phi}{2}) + \cos\phi_1\cos\phi_2\sin^2(\frac{\Delta\lambda}{2})$$
$$c = 2\,\text{atan2}(\sqrt{a}, \sqrt{1-a})$$
$$d = Rc$$

4. Calculation of the timing:

$$d = u * t + \frac{1}{2}a * t^2 \qquad d = vt$$

Advisory Messages

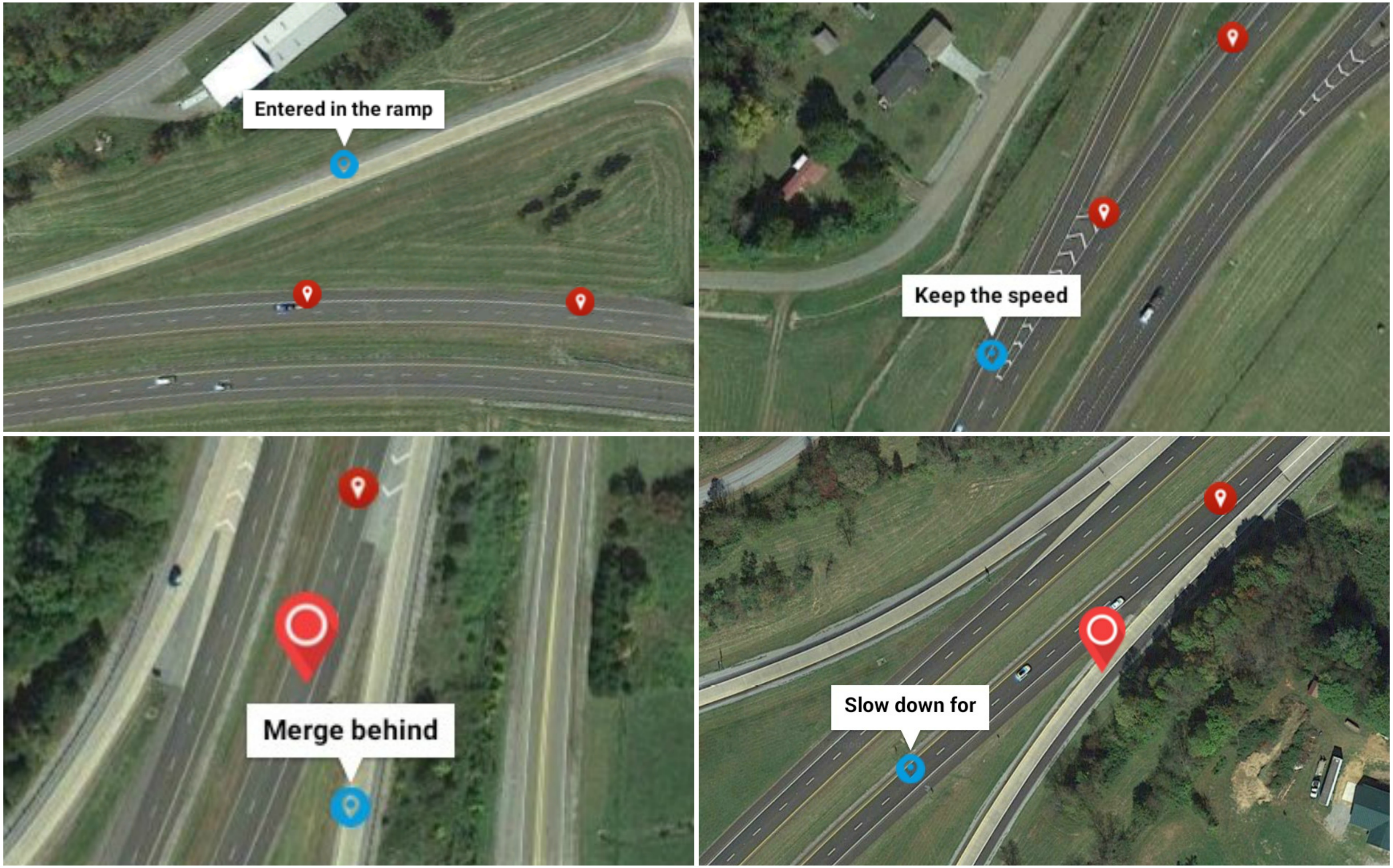
- All vehicles receive and synchronize the timing information using CTRL & SYNC messages.
- Then each vehicle generates advisory messages for itself.
- Four different advisory messages used:
  - Notify the presence of a merging vehicle on ramp
  - Advise the driver to maintain the speed
  - Advise the driver to merge behind a specific vehicle
  - Advise the driver to slow down to allow merging in front

Evaluation of the Model

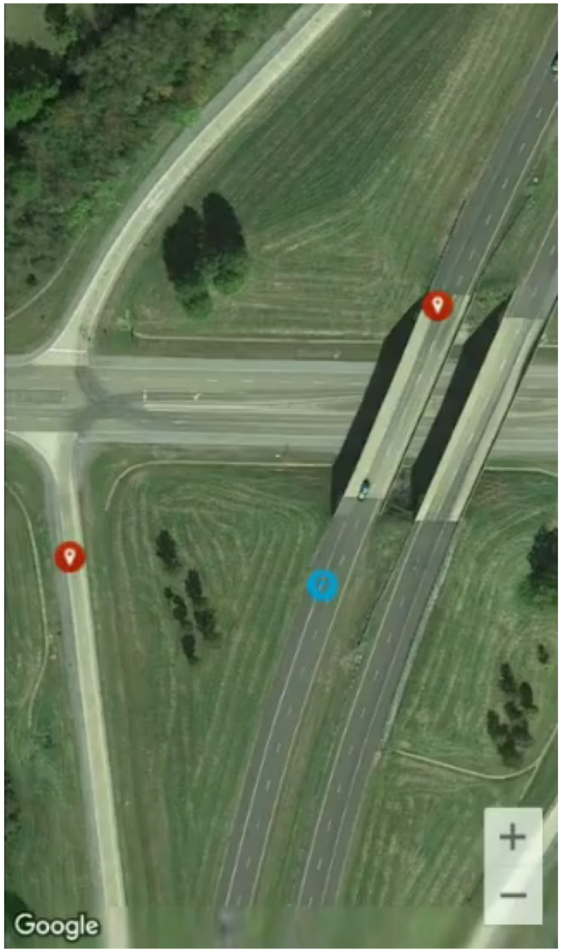
- Evaluated our model for 8 exits in I-26
  - Exit 27 West Bound & East Bound
  - Exit 32 West Bound & East Bound
  - Exit 34 West Bound & East Bound
  - Exit 36 West Bound & East Bound

- Experimental Setup inside vehicle

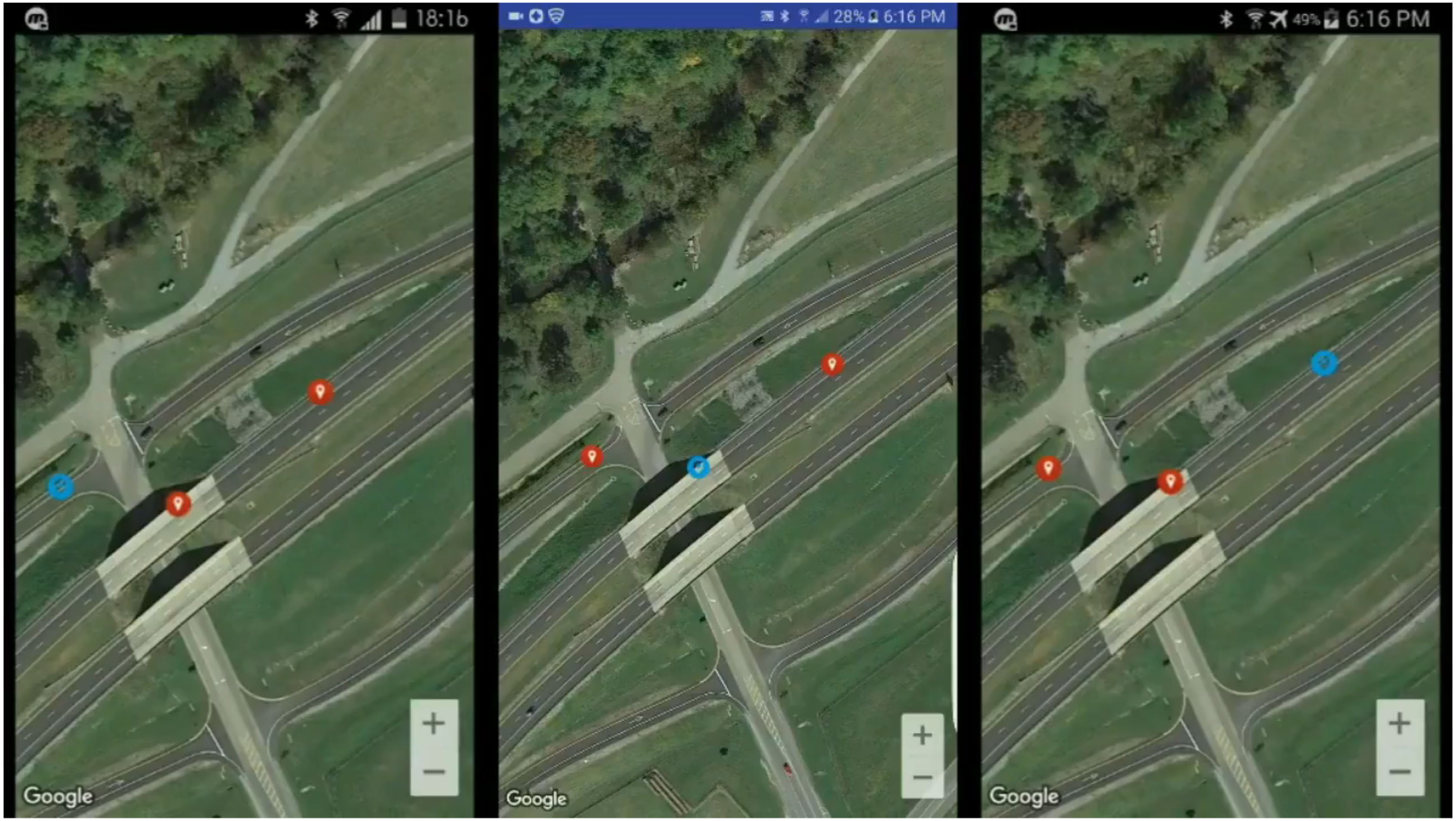
Screenshots of Advisories



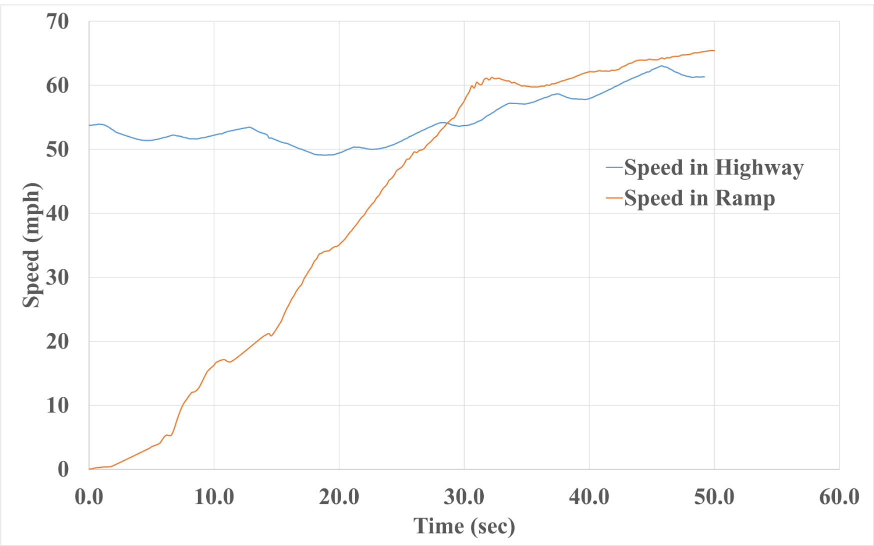
Advisory & Alert Messages in the Android App (VIDEO 1)



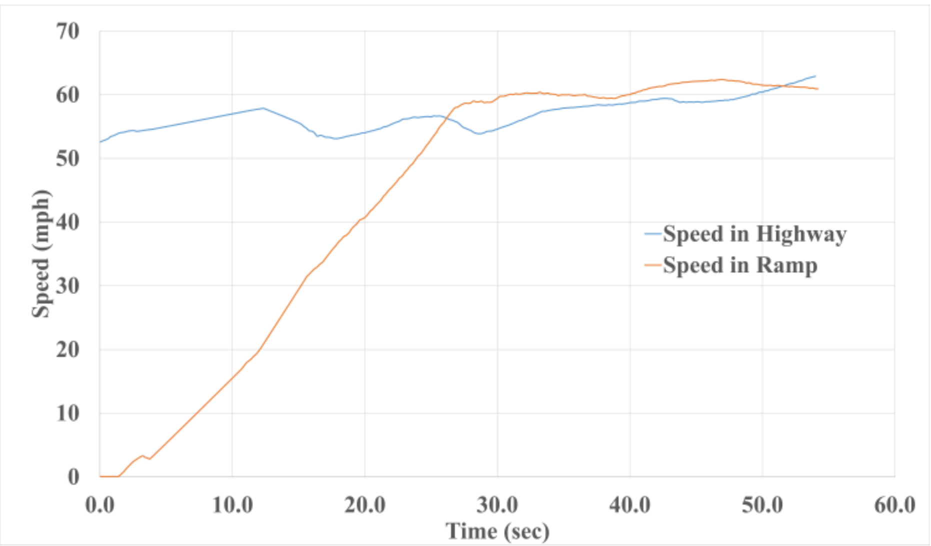
Advisory & Alert Messages in the Android App (VIDEO 2)



Preliminary Data Analysis

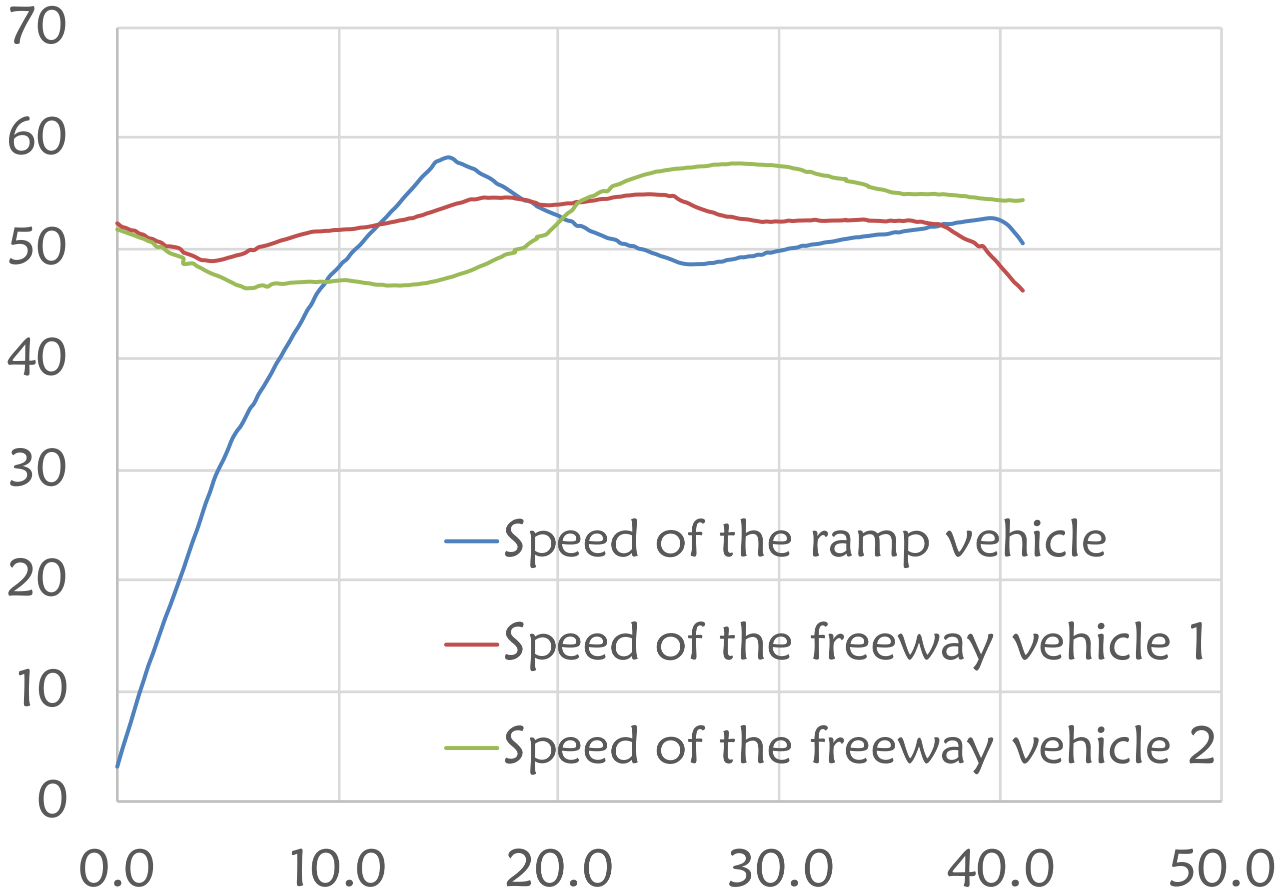


Exit 27 (East Bound)



Exit 27 (West Bound)

Result Analysis



Average speed
vehicle 1: 52.32mph)
vehicle 1: 52.20mph)

Average acceleration
1.155 m/s^2
Or
(2.58 mph/s)

Future Plans

- Consideration of circular ramps.
- Lane detection mechanism.
- Discarding mechanism for non-conflicting vehicles.
- Automatic cruise control feature.

Research Goal 2

A Parallel Simulation Framework

Background

Simulators	Two simulation models of a simulator	
	Mobility model	**Network model**
ASH	IDM/MOBIL, IVG	SWANS
OVNIS	SUMO	NS-3
STRAW	Developed their own model	SWANS
Veins	SUMO, IVC	OMNET++
VnetIntSim	INTEGRATION	OPNET
TraNS	SUMO	NS-2
iTETRIS	SUMO	NS-3
GrooveSim	Developed their own model	Their own network model
Automesh	Customizable to add any mobility model	NS-2 or Qualnet

Challenges of a Parallel Simulator

Scope of this thesis

- Partitioning of the Complex Transportation Network.
- Reducing Inter-Simulator Communication Overhead.
- Existence of heterogeneous vehicles.
- Synchronization problem.
- Scalability of Parallel Simulation.

Research Goal 3

Transportation Network Partition

Network Partitioning: Parameters

- Traffic parameters extracted from openstreetmap.org (OSM data)
  - Node weight
  - Link Length
  - Number of lanes
  - Link density (approximated)
  - Link priority

Experimenting with METIS

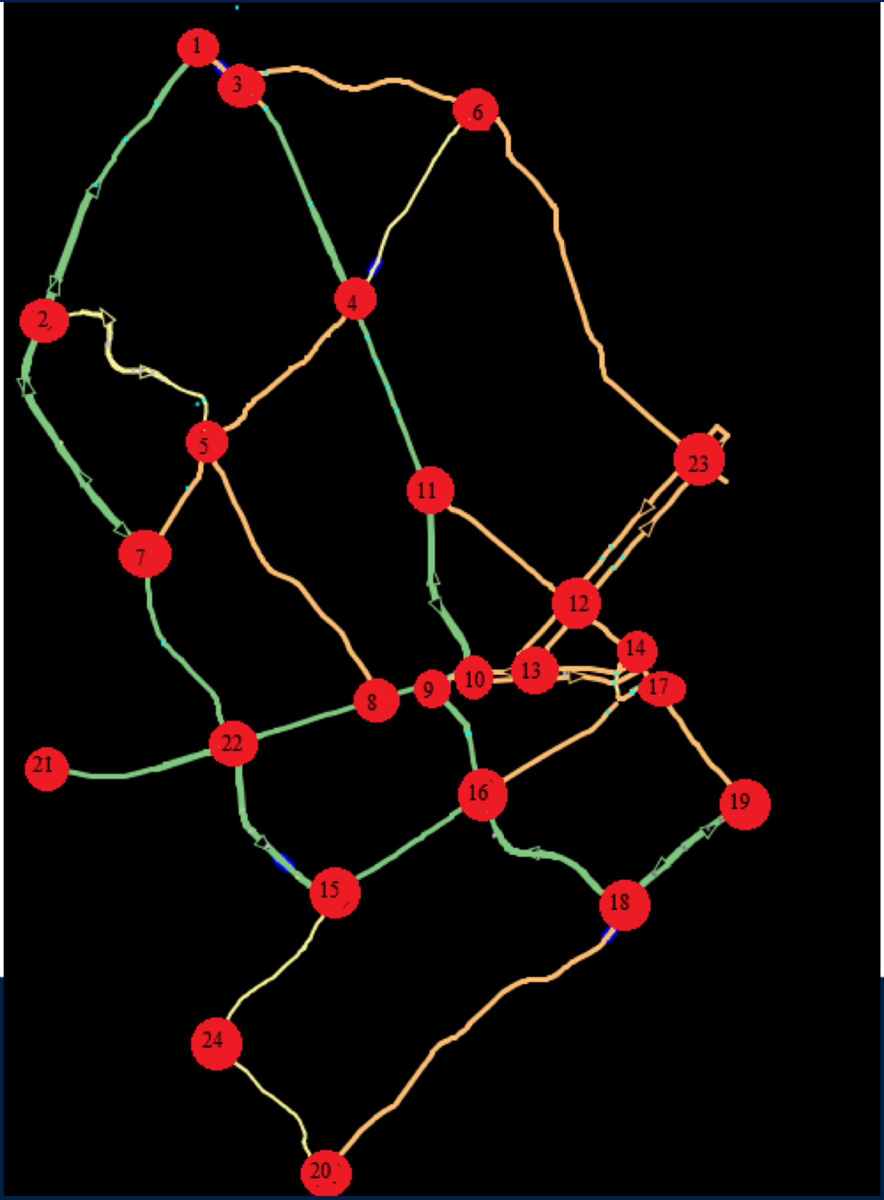
For the road network of Johnson City, TN.

# partition	Communication cost (given by METIS)	
	Without traffic parameters	With traffic parameters
2	10	9
3	13	12
4	22	21
5	23	25
6	30	27

$$totalv = \sum_{v \in V_b} Nadj[v].$$

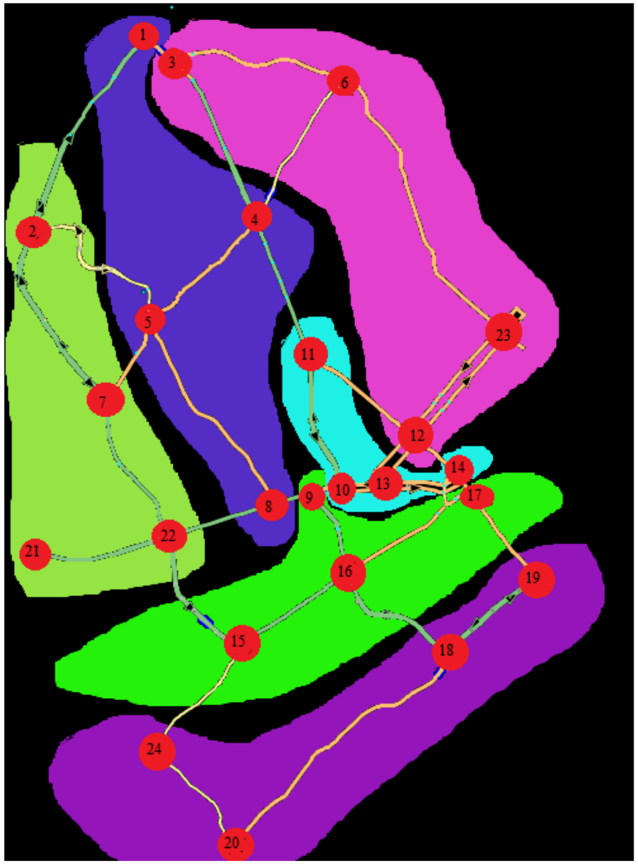
N adj[v] be the number of domains other than P[v]

P be a vector of size |V |

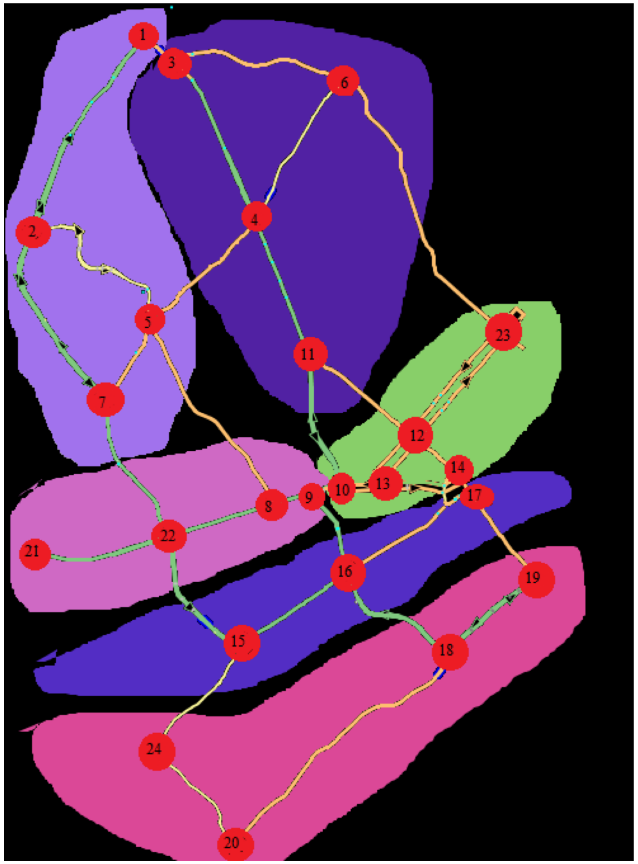


Experimenting with METIS (Cont'd)

Without traffic parameters



With traffic parameters



Research Goal 4

Investigation of the inter-simulator communication overhead

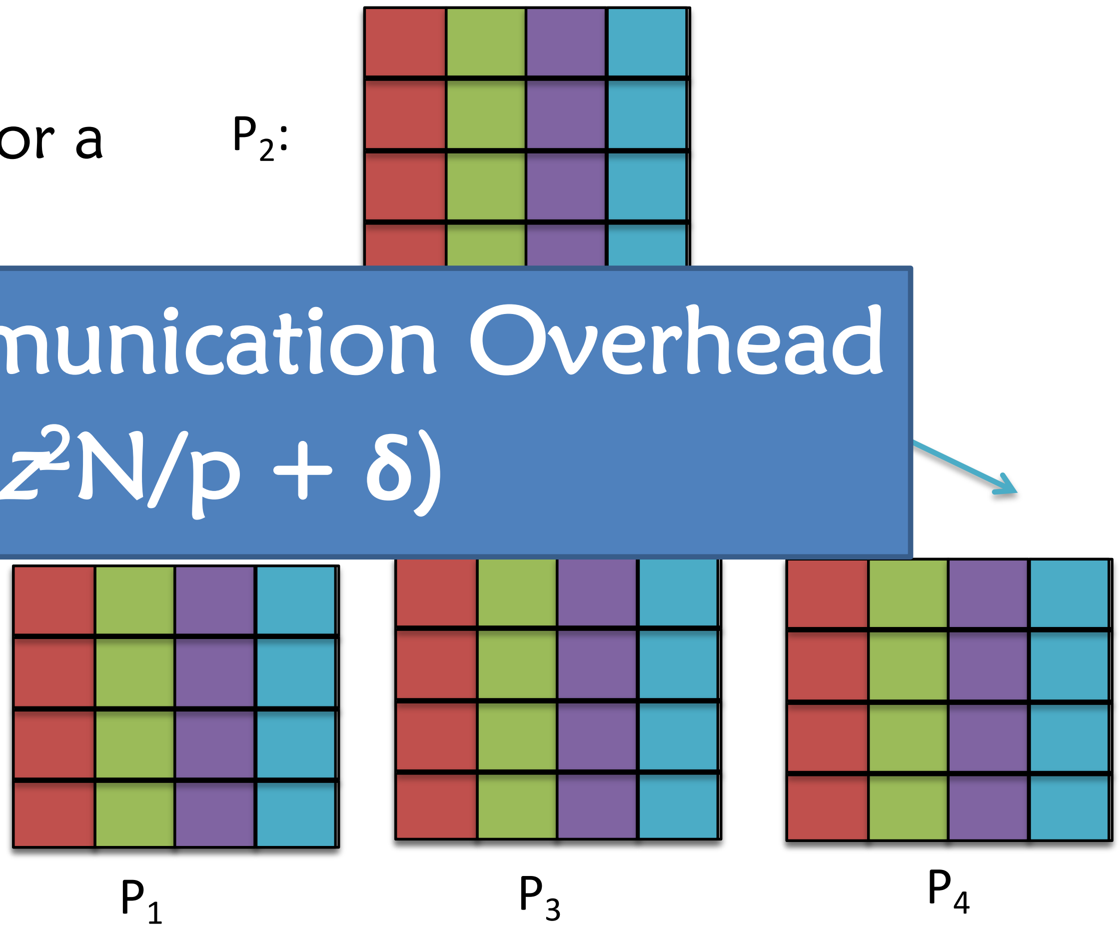
Background: Linear Algorithm

A **linear** partial results accumulation algorithm for a **distributed matrix-matrix multiplication** (

Each process se

receives partial results

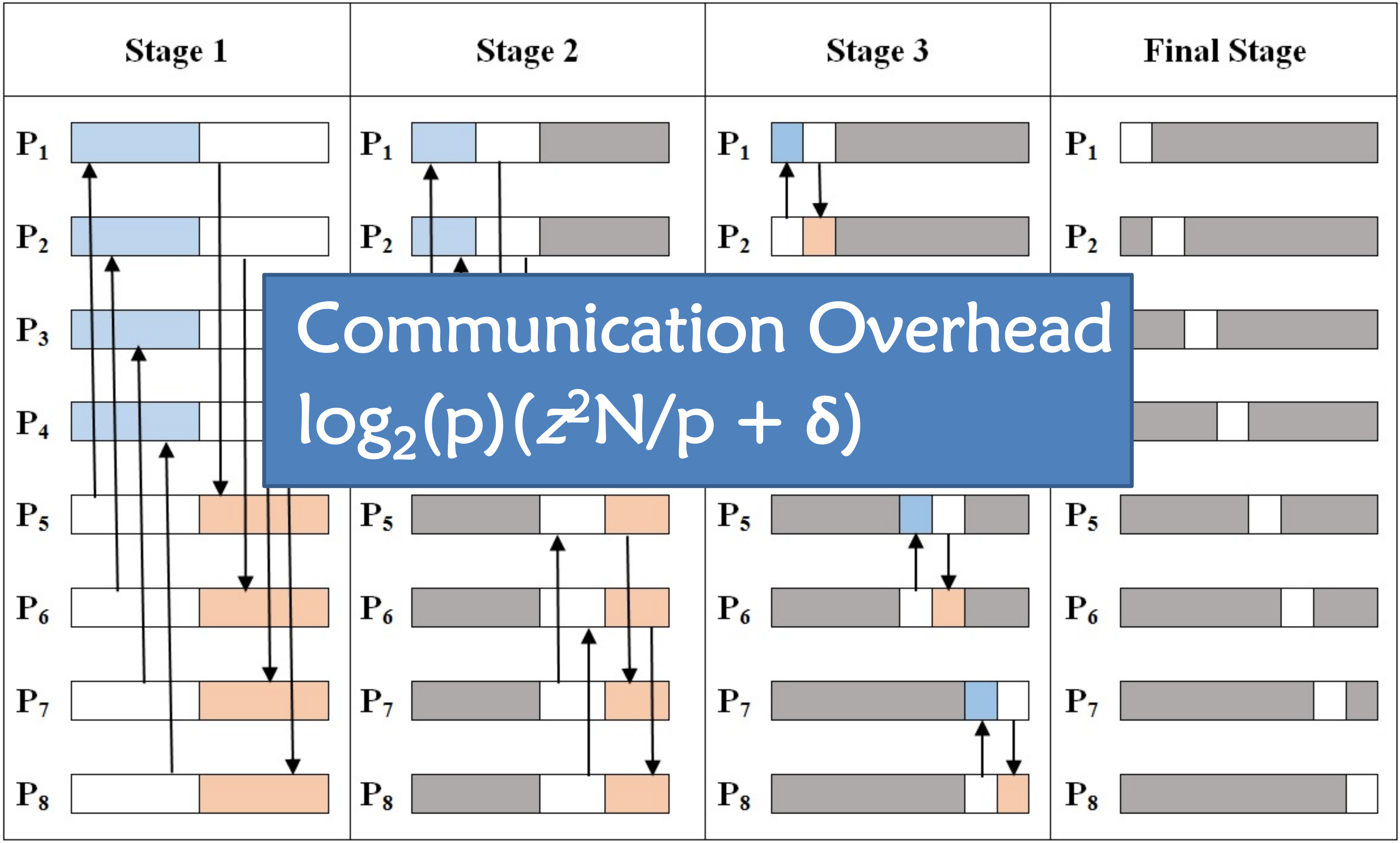
from other processes



Communication Overhead

$(p\text{-}1)(z^2N/p + \delta)$

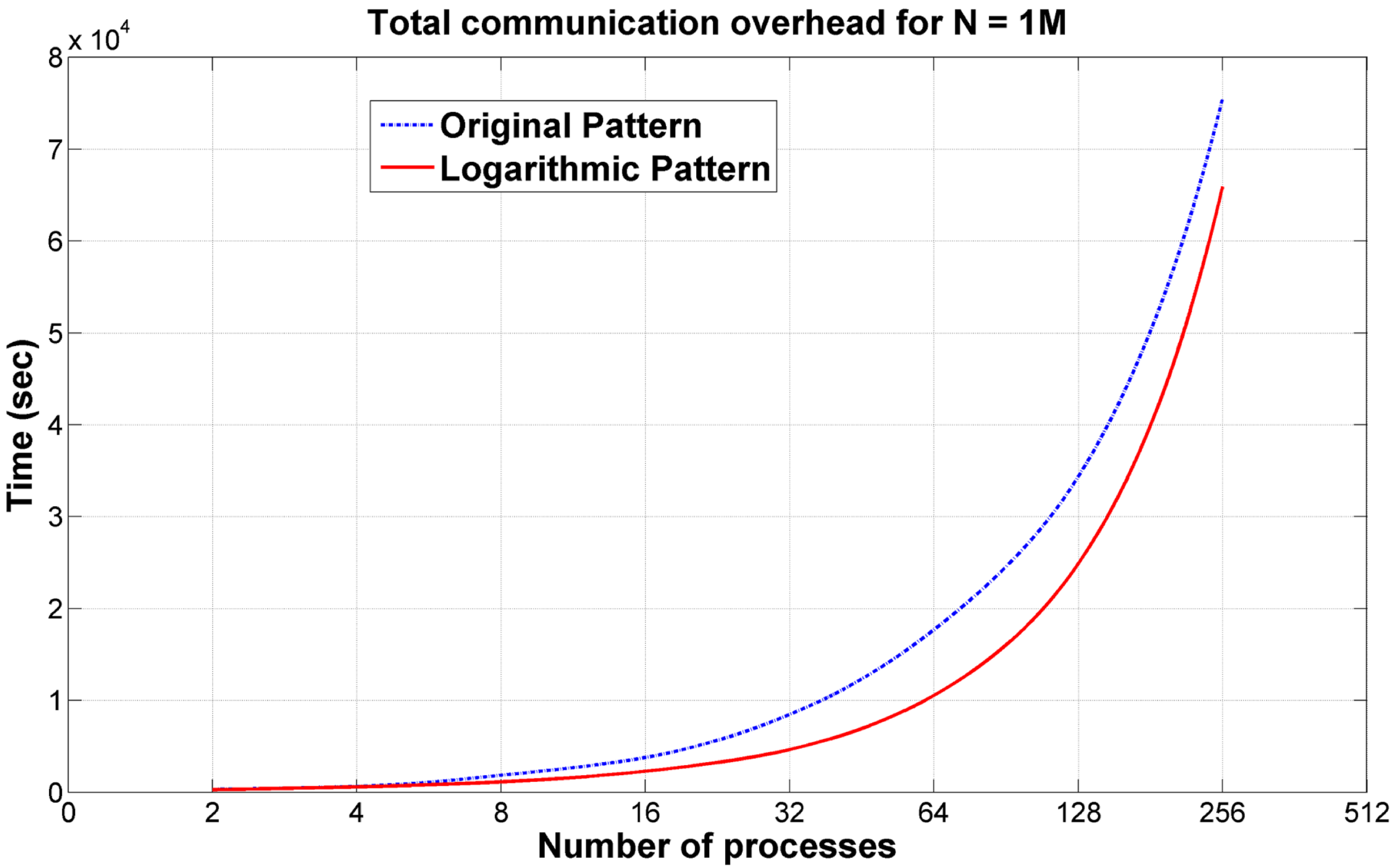
Logarithmic Algorithm: Summary



Communication Overhead

$\log_2(p)(z^2N/p + \delta)$

Performance Analysis (Cont'd)



Concluding Remarks

- Improvement of the freeway merge assistance system
- Development of the simulation framework
- Improvement of the partitioning scheme

References

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2. Md Salman Ahmed, Mohammad A Hoque, Demo: Real-time Vehicle Movement Tracking on Android Devices Through Bluetooth Communication with DSRC Devices, IEEE Vehicular Network Conference, IEEE VNC 2016.
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5. Md Salman Ahmed, Jennifer Houser, Mohammad A Hoque, Phil Pfeiffer, Reducing Inter-Process Communication Overhead in Parallel Sparse Matrix-Matrix Multiplication, ACM Mid-Southeast Conference 2016. (Best paper award, Masters Category, third prize)
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8. Md Salman Ahmed, Mohammad A Hoque, Brian Bennett, Mohsen Kamrani, Asad Khattak, “Freeway Merge Assistance System using DSRC”, IEEE Trans- actions on Intelligent Transportation Systems (In preparation)

Questions