Energy-Aware Dynamic Data-Driven Distributed Traffic Simulations

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- Monitor system-wide real-time traffic conditions (ITS, instrumented vehicles)
- Map travel behavior responses to system perturbations over time
- Link data analysis with distributed simulation
- Estimate energy use, time, and cost tradeoffs for alternative departure times, modes, and routes
- Deliver tailored messages to participants to influence travel decisions and monitor outcomes
- Application to vehicle tracking

Massive, centralized simulation models are costly, difficult to maintain, and cannot easily interact with all travelers in large metropolitan areas to provide personalized travel advice.

Next generation, agile, distributed, real-time simulation on network computers and agent devices will predict traffic conditions, advise travelers, and influence travel choices.
Research Components

- Data-driven vehicle trajectory prediction combining real-time data analytics and simulation
- Emission and fuel consumption prediction
- Energy-aware distributed simulation middleware
Distributed Simulation

- Agent simulations predict near-future, corridor-level traffic conditions on alternative o-d pathways
- Travel times and congested speed/acceleration profiles for agent advising
- V2V communications enhance modeling efforts
- Criteria: minimal
  - Power requirement (computation)
  - Flexible for future refinement
Two Approaches - Philosophies

Cellular Automata
• Models all vehicles on the corridor
• Microscopic Traffic Dynamics – behavior of individual vehicles
• Simple rules
• Computationally efficient
• Discrete time advancement

Bayesian Inference
• Models single vehicle
• Predict vehicle trajectory
• Based on data mining and statistical methods
• Minimal computational demands
Two Approaches – Tradeoffs

**Cellular Automata**
- Captures congestion dynamics
- Input data intensive – traffic demands, control, geometry, etc.
- Simulate traffic dynamics during incident
- Output individual vehicle and network level performance metrics

**Bayesian Inference**
- Requires probe vehicle data (PVD)
- PVD reflects demand, control, etc.
- Bayesian adjustment based on dynamic data
- Output individual vehicle trajectory
- System estimation based on aggregation of multiple clients
The Future (Present?) of Data

Vehicle Based Data

NGSIM: Peachtree St., Atlanta, Ga

- FHWA’s Next Gen. Simulation
- 30-minute data at 0.1s resolution
- 2100 ft., 35 mph, 4-5 lanes
- Midblock sources and sinks
- 1222 unique vehicle trajectories
- ~90 vehicles go end to end
- Per lane data
Sample Simulation Trajectory Results

Cellular Automata

Bayesian Inference
Emission Modeling - MOVES-Matrix and NGSIM Data

NGSIM Speed Traces Pre-processing:

- Smooth speed-time traces
- Take derivative of smoothed speed for accel

Example of Raw Speed Traces (10 Hz) vs. Smoothened Speed Traces (1 Hz)

Derivative of Smoothened Speed for Acceleration
Emission Modeling with MOVES-Matrix

- Calculate VSP
- Allocate operating mode bin
- Assign emission rate

\[
VSP = \left( \frac{A}{M} \right) v + \left( \frac{B}{M} \right) v^2 + \left( \frac{C}{M} \right) v^3 + \left( \frac{m}{M} \right) (a + g \cdot \sin \theta) v
\]

- M = Fixed mass factor (tonnes) for the source type
- m = Source mass (tonnes), m equals M for LDVs
- A = Rolling resistance (kW/meter/second)
- B = Rotational resistance (kW-second^2/meter^2)
- C = Drag coefficient kW-second^3/meter^3
- v = Vehicle velocity (meters/second)
- a = Vehicle acceleration (meters/second^2)
- g = Gravitational acceleration (9.81 m/second^2)
- θ = Road grade angle (radians or degrees, as needed)
Example: Vehicle Speed and NOx emission rate

Cumulative Sorted NOx Emissions by Time

Cumulative Sorted Fuel Consumption by Time

Cumulative Sorted CO Emissions by Time
• Distributed Simulation Middleware needed to interconnect simulations, sensors, databases, space-time memory, ...
• Services for system management, communications, synchronization
• Examples: HLA (IEEE 1516), DIS (IEEE 1278), TENA
Green Run-Time Infrastructure (GRTI)

- Energy efficient synchronization algorithms (time management)
- Energy efficient data dissemination (data distribution management)
- API supporting application controlled energy optimization
  - Energy optimized data subscription (e.g., reduced client request messages)
  - Data aggregation
- Scalable, support wide variety of devices
GRTI Architecture

Network (Internet/Ad-hoc)

Server

Apache

HTTP SERVER PROJECT

FastCGI (mod_fcgii)

Global Sync Module

CppCMS controller

Message Aggregator Module

Push Message Module

IOT devices as Clients

Any network (Internet, private, Ad-hoc etc.)

Widely used webserver & backend: scalable

Webserver: More freedom for client development
Energy Consumption: Message Aggregation

Experimental setup

- **Client**: Android Smartphone (Google Nexus 5), Android OS v 5.1
- **Server**: Lenovo Thinkpad laptop (T410s), Ubuntu 14.04
- **Communications**: 802.11n

- Client: Cellular automata based traffic simulation (Rickert et al. 1996) for segment of Peachtree Ave. in midtown Atlanta
  - Simulation sends stream of vehicle position updates via GRTI (12 bytes per update)
- Aggregate updates at sender before sending
- Initial reduction in energy with increased aggregation due to reduced number of message sends
- Increased aggregation
  - Increased energy when multiple packets required
  - Aggregation results in increased delay
Power Consumption: Simulation vs Communications

- **Simulation**
  - Peachtree Street, midtown Atlanta (NGSIM study area)
  - Cellular automata and queueing models
- **Data streaming**
  - Continuous stream of messages
  - Power to send messages dominates
- **Energy for communications dominates**
  - NGSIM area modest in size
Future Work

• Energy Efficient Methods for Data-Driven Distributed Traffic Simulations
• Set Bayesian Inference Implementation (backward and forward (n) intersection match, (k) previous users, sub path updates, etc.)
• Implement Bayesian Inference using V2V Basic Safety Message (BSM)
• Validate against large scale model
• Dynamic update for network level travel route changes