Internet of Vehicles: From Intelligent Grid to Autonomous Cars and Vehicular Clouds

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The Genesis of IOT

- **Pervasive embedded sensors in environment**
  – Eg home sensors
- **Sensors interact with users**
  – People set thermostats, turn off lights, turn on video
  – There is a pattern in their behavior
- **Sensor + users data => User behavior models**
  – Sensor data uploaded to Cloud (with 5G);
  – Machine Learning infers people behavior;
  – this in turn is used for smart energy reallocation
- **IOT: sensors + people + 5G + Cloud + actuators**
- **Stakeholders: DOE, Medical Providers, Merchants**

Internet of Vehicles = Internet of Many Things

The Vehicular "Things" :

- **External sensors (GPS, cameras, Lidars etc)**
- **Internal automotive sensors and actuators (brakes, steering wheel, accelerator, driver behavior, etc)**
- **Internal cockpit sensors (driver's state of health, alertness, tone of voice, Ford heart monitor seat, etc)**
- **Driver's messages (tweets, Facebook, other crowd-sourced info, etc)**
- **The entire vehicle as a source of messages, alarms**
- **Stakeholders: Insurance, DOT, Law Enf. Agents, etc**

Evolution from instrumented car to IOV

- **Vehicular Things (eg alarms), what to do with them?**
  - Initially, the driver reacted only to non real time measures, like oil pressure, water temperature, fuel level; no record keeping,
  - as cars get smarter: track more sensors (computer assisted driving)
  - Also, upload info to cloud; learn about driver – this can interest Insurance Companies
- **Cars are evolving to become full fledged IOT platforms**

Similarities in IOV and IOT in Energy

Vehicle evolution	Smart Grid/IOE (energy)
Manual first	Manual setting of thermostat
Cloud assisted. (navigator, intelligent highway, lane reservations, multimodal transportation)	Cloud controlled guidance in settings to human operators.
Self driving autonomous cars ▪ For comfort on freeways and for safety on surface roads ▪ Here, vehicle interactions (via V2V communications) are CRITICAL	Intelligent buildings and energy grids ▪ Full automation – sensors/actuators select best operating conditions (for energy savings and human comfort) ▪ Mostly still controlled from BIG cloud; but considerable local autonomy; limited P2P interaction between Energy Things

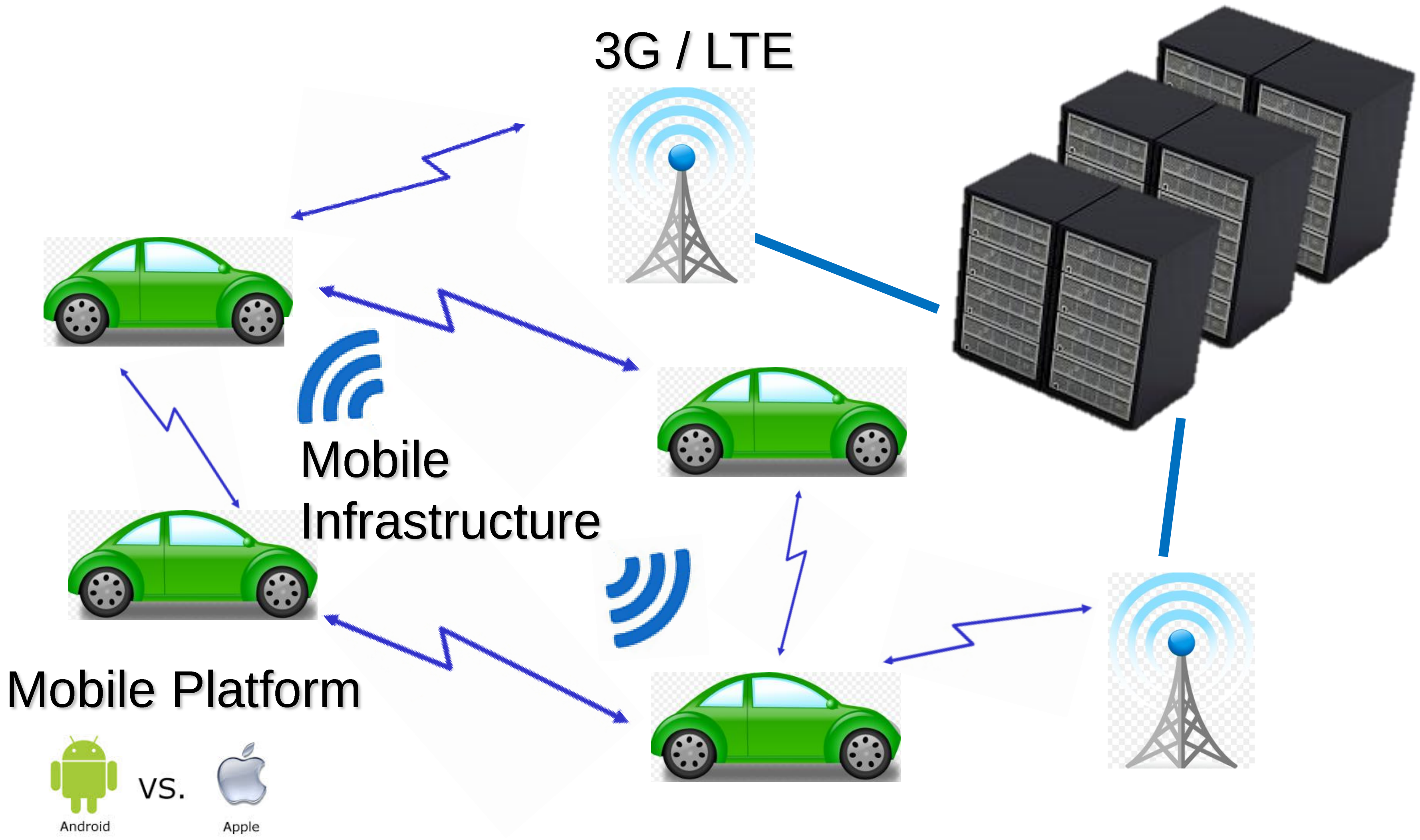
What Makes IOV Unique

- **Mobility:**
  - Must manage mobility and **wireless bottleneck**
  - Must guarantee **motion privacy**
- **Energy**
- **Safety critical Apps**
- **V2V:**
  - Critical for safety, low latency apps (eg, platoons)
  - Man cannot be completely removed from control loop because of safety
- **Attacks**
  - Must protect from hackers and malicious agents

IOV and Vehicle Computing Cloud

- **Internet Cloud (eg Amazon, Google etc)**
  - Data center model
  - Immense computer, storage resources, connectivity
  - Services, virtualization, security
- **Mobile Cloud (traditional)**
  - What most researchers mean:
    - Access to the Internet Cloud from mobiles (eg MSR Maui)
    - Access to Edge Cloud (eg Cloudlet, etc)
    - Tradeoffs between local and cloud computing (eg m-health)
- **Now, the Mobile Vehicle Cloud (MVC)**
  - IOV creates powerful platforms (storage, process, sensors)
  - Vehicles run distributed applications not suited for Amazon

Mobile Computing Cloud



Why Vehicular Cloud?

Observed trends:

1. **Vehicles are becoming powerful sensor platforms**

   GPS, video cameras, pollution, radars, acoustic, etc

2. **Spectrum is scarce => Internet upload expensive**

3. **More data cooperatively processed by vehicles**

   V2V road alarms (pedestrian crossing, electr. brake lights,platoons, intersections, etc)

   Surveillance (video, mechanical, chemical sensors)

   Environment mapping via "crowd sourcing"

⇒ From VANET to IOV and Vehicular Cloud

Road Map

- It all started with DOT
- Vehicle Applications Overview
- Closer look at Road Safety, Intelligent Transport and Security Services
- Future Outlook for IOV and Vehicle Clouds

The Vehicle Transport Challenge

Safety

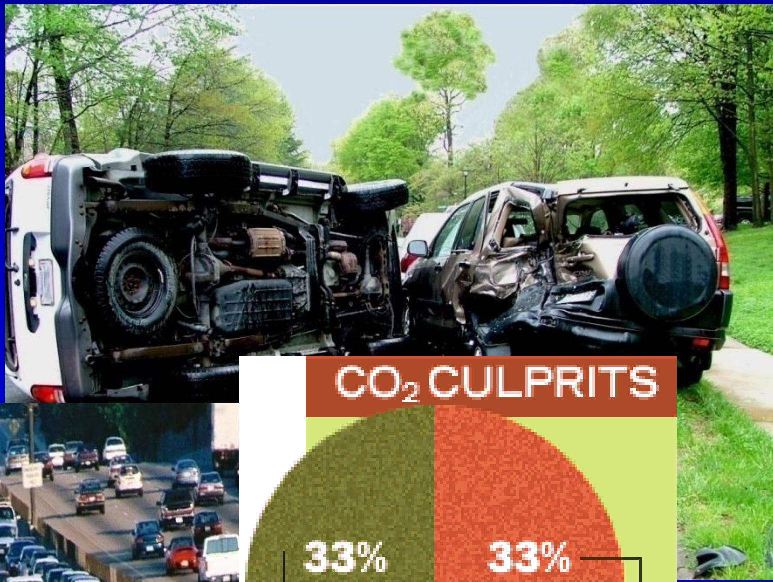
- 33,963 deaths/year (2003)
- 5,800,000 crashes/year
- **Leading cause of death for ages 4 to 34**

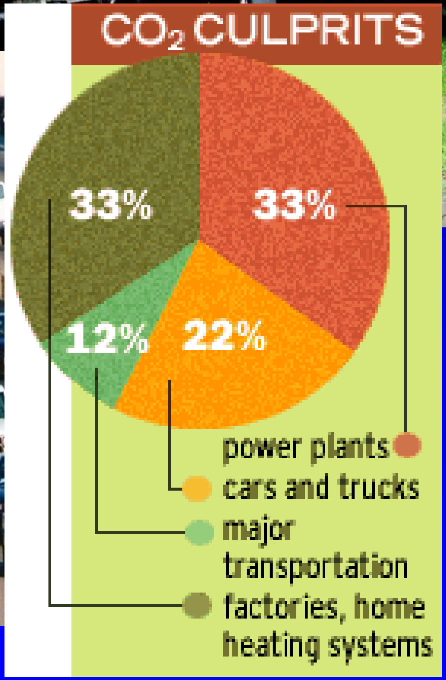
Mobility

- 4.2 billion hours of travel delay
- $78 billion cost of urban congestion

Environment

- 2.9 billion gallons of wasted fuel
- 22% CO_2 from vehicles





In 2003 DOT launches: Vehicle Infrastr. Integration (VII) - 2003 to 2009

- **VII Consortium: USDOT, automakers, suppliers, ..**
- **Goal: V2V and V2I comms protocols to prevent accidents**
  - Technology validation;
  - Business Model Evaluation
  - Legal structure, policies
- **Testbeds: Michigan, Oakland (California)**
- **Standard: DSRC (Ded. Sh. Range Comm), 5.9Ghz**
- **However: 10 year to deploy 300,000 RSUs and install DSRC on 100% cars**
- **Meanwhile: can do lots with 3G and smart phones**
  - Can we speed up "proof of concept"?

Enter Connected Vehicle (2009-2014)

Connected Vehicle Program(2009-14)

- ***Safety → DSRC***
  - Aggressively pursue V2V
  - Leverage nomadic devices to accelerate benefits
  - Retrofit when DSRC becomes universally available
- ***Non-safety (mobility, environment)***
  - Leverage existing data sources & communications; include DSRC as it becomes available

US DOT endorses V2V in Jan 2014

– *This stimulates research on V2V Clouds*

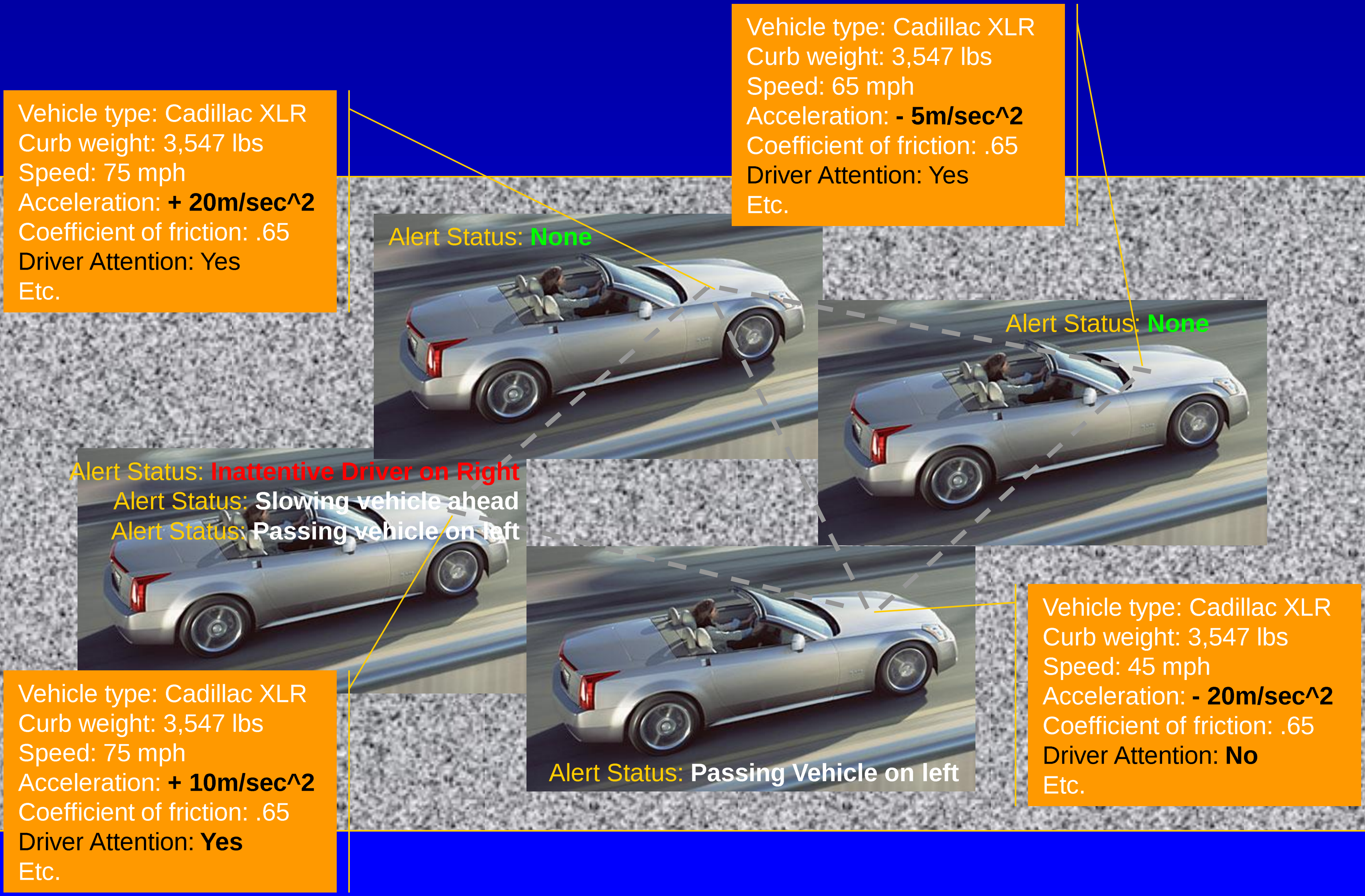
V2V in Emerging Applications

- **Safe Navigation**
  - Crash prevention; platoon stability; shockwaves
- **Content Download/Upload**
  - News, entertainment, location relevant info download; ICN
  - Video upload (eg remote drive, Pic-on-wheels, accident scene, etc)
- **Sensor Data gathering**
  - Forensics; driver behavior; traffic crowdsource; ICN
  - Privacy preserving data analysis
- **Intelligent Transport**
  - efficient routing to mitigate congestion/pollution
- **Increased Vehicle Autonomy**
  - Platoons, autonomous vehicles, etc

V2V for Safe navigation

- **Forward Collision Warning,**
- **Intersection Collisions**
- **Traffic shockwaves**
- **Platooning (eg, trucks)**
- **Advisories about road perils**
  - "Ice on bridge", "Congestion ahead",….

V2V communications for Safe Driving



Do we really need V2V to Protect Self Driving Vehicles?

- **Auton. vehicles very instumented (GOOGLE):**
  - Acoustic, Laser, Lidar
  - Video Cameras
  - GPS, accelerometer, etc
- **Google car approach: use sensors (instead of V2V) to protect the car**
- **The future invalidates Google's claim:**
  - Thousands of autonomous vehicles will share the road
  - Advance platooning
  - Very high speeds and short car to car gaps
  - The "isolation via sensors" model requires 40m gap!
- **Autonomous vehicles will require even more V2V**

V2V for Platooning

Studies point to need for V2V coordination

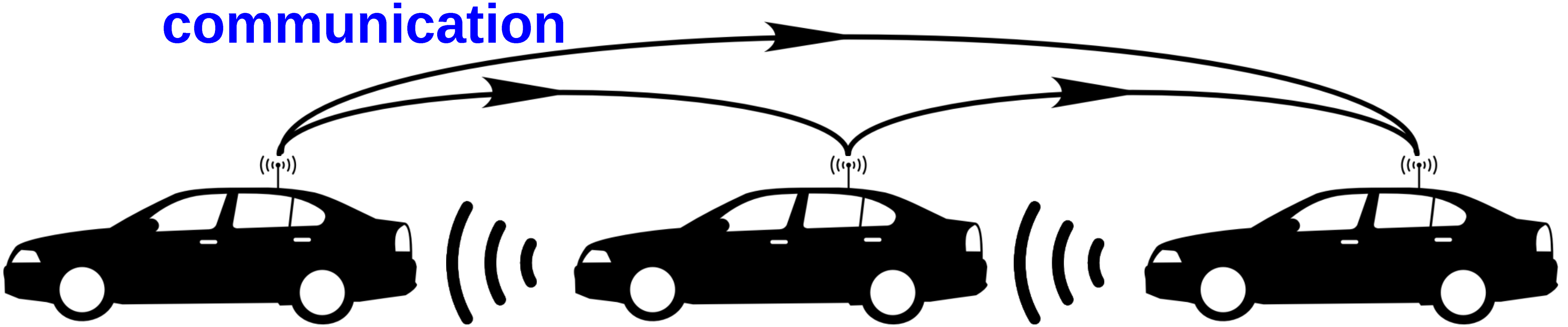
Autonomous Vehicle Control

V2V more critical as autonomous car penetration increases

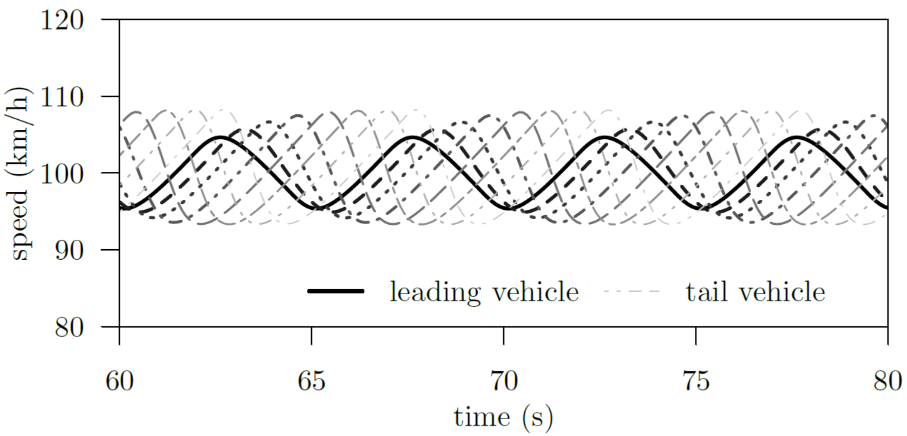
Platoon Control Systems

- Standard ACC: radar (or lidar) based

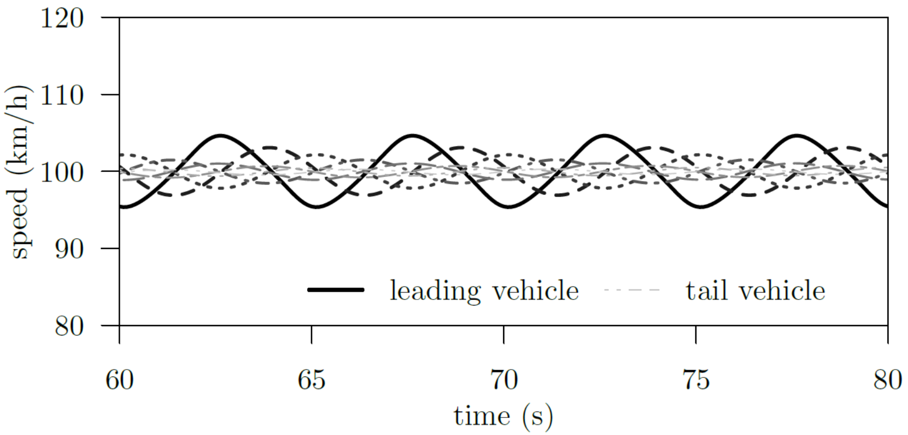
- Cooperative ACC (CACC): radar + wireless communication



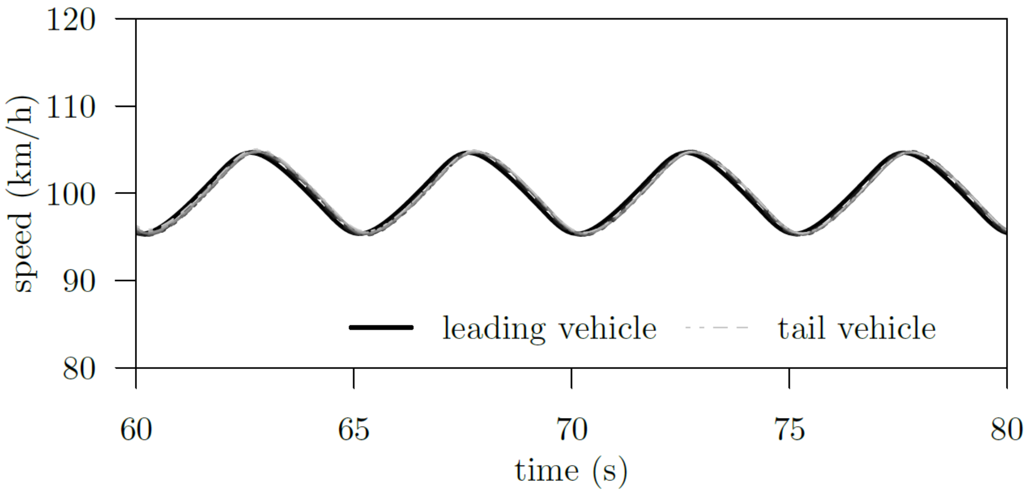
Controllers comparison



ACC – headway T = 0.3 s



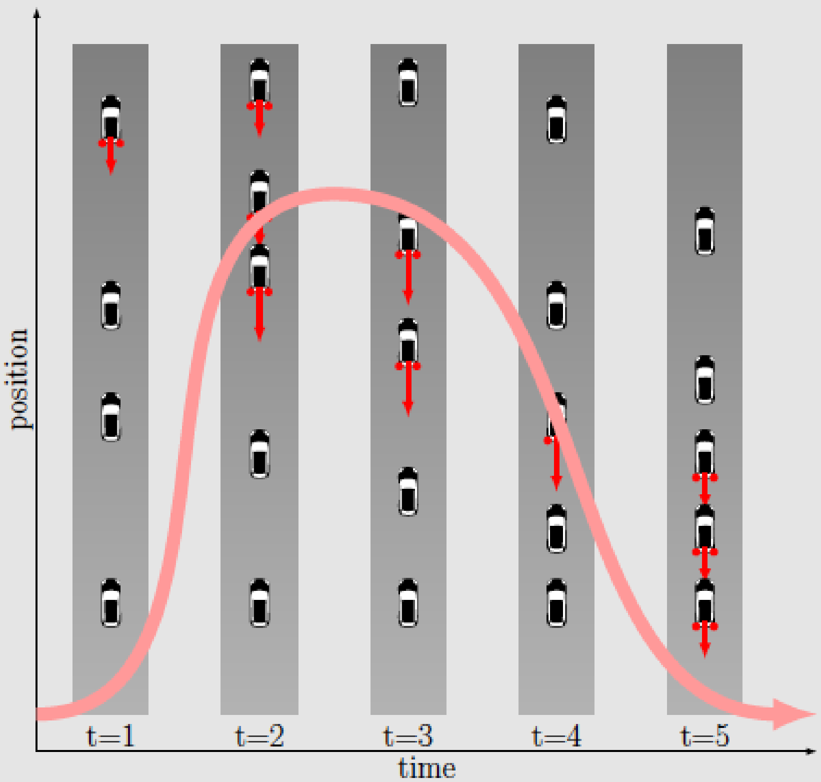
ACC – headway T = 1.2 s



CACC – distance = 5 m

Traffic Shock Waves

Traffic shock waves on congested highways



Reasons

- high traffic demand
- unexpected driver actions
- human reaction time
- physical perturbations
  - ramps
  - construction sites
  - reduction of lanes

Consequences

- hard breaking maneuvers
  - waste of energy
  - increase in emissions

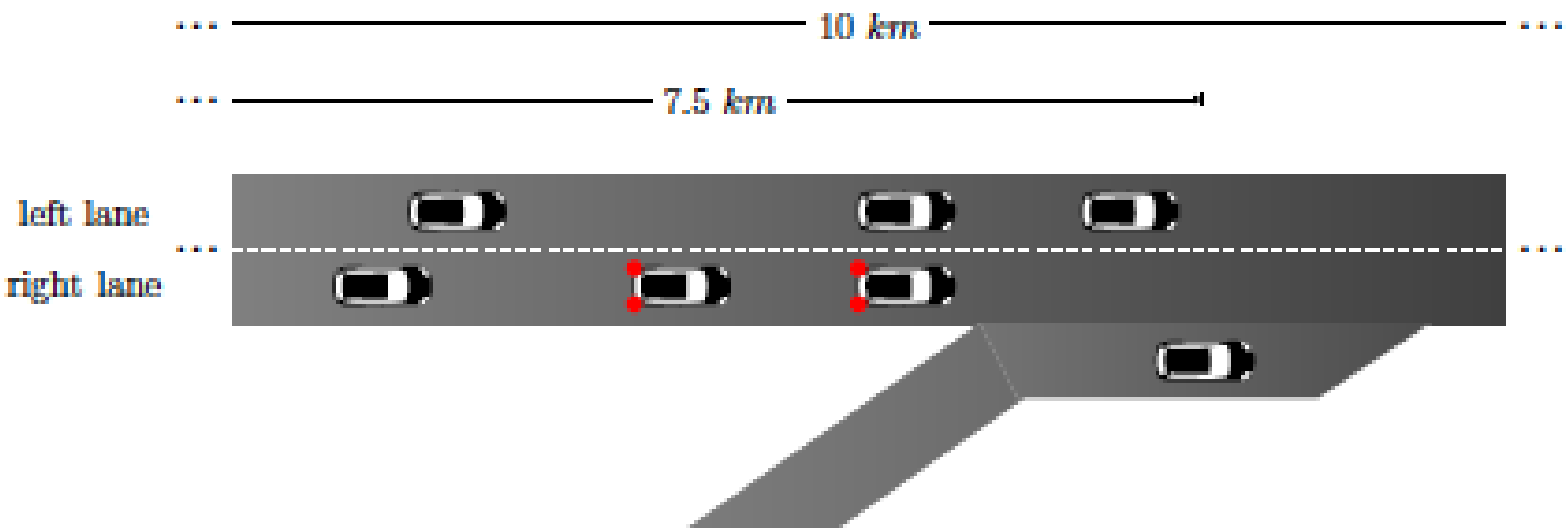
Current Technology – ADAS (Advanced Driver Assistance System)

- Features
  - one-hop information
  - unidirectional
  - limited monitoring horizon
- Applications
  - assisted breaking
  - traffic sign recognition
  - adaptive cruise control
  - variable message sign

DRIVE (Density Redistribution via Intelligent Velocity Estimates)

- new Vehicle to Vehicle communication protocol
  - distributed
  - connectionless
  - event driven
  - multi-hop
- estimate traffic conditions in the interspace between two vehicles
  - in communication range
  - in the same lane
  - in congested phase
- traffic slow down ahead

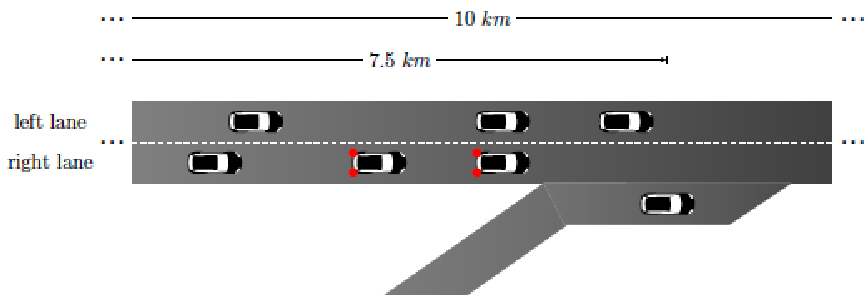
Simulation Experiment



Evaluation (INFOCOM 14)

Simulation Setup

- SUMO + TraCI
- V2V communication in Python
- Krauss car-following model
- 2 lane highway + onramp
- Different vehicle classes
- Simulation Time $T = 7200$ s

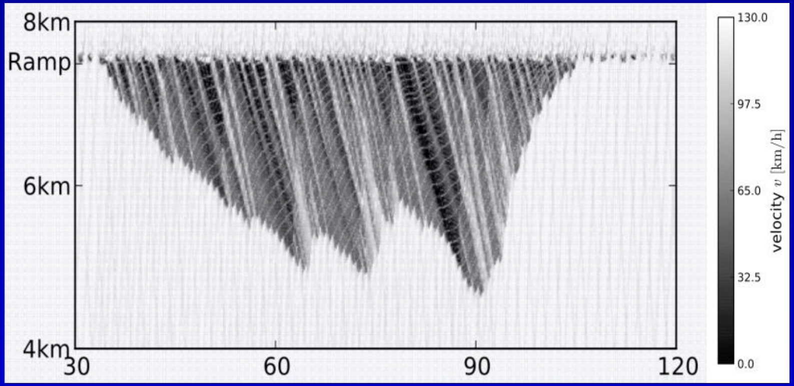


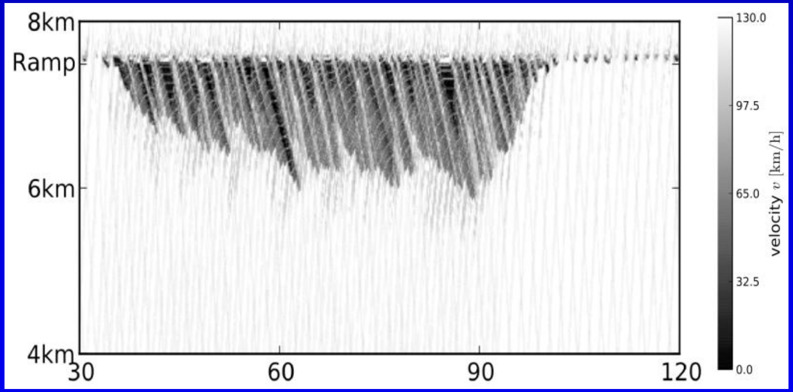
Traffic demand

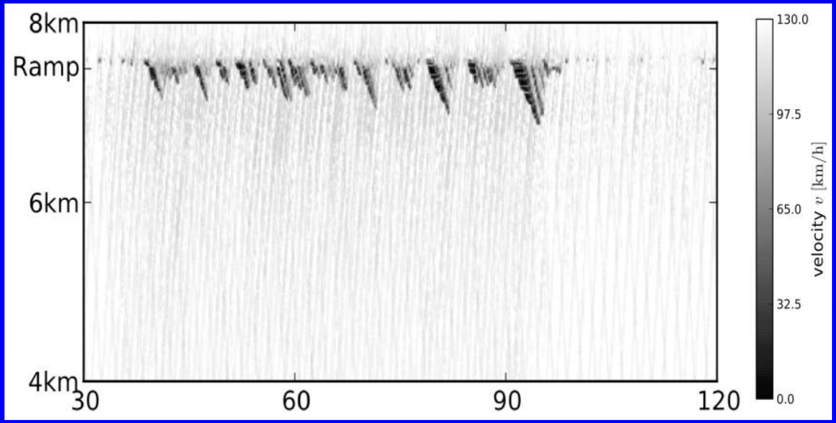
- T_1 0 – 30 mins **low** 800 veh/h/lane
- T_2 30 – 90 mins **high** 1300 veh/h/lane
- T_3 90 – 120 mins **low** 800 veh/h/lane

class	l_{eff} $[m]$	a_{max} $[m/s^2]$	b_{max} $[m/s^2]$	overall %
A	7.5	2.5	−4.5	47.5
B	7.0	1.5	−4.0	47.5
C	17.0	1.2	−4.0	2.5
D	20.0	0.7	−4.0	2.5

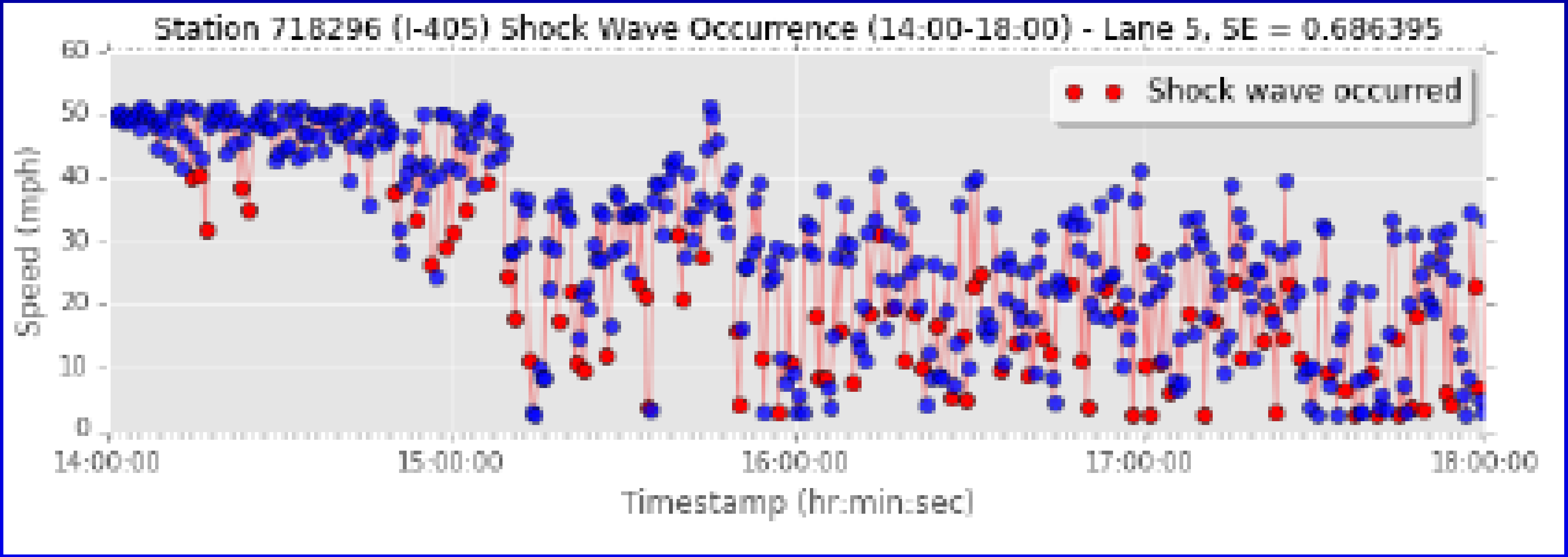
Simulation Results







Shockwaves in LA, 405 FWY (PeMS data)



- PeMS loop sensor file is analyzed using Dynamic Bayesian Network Models to detect shockwaves
- PeMS = Performance Measurement System supported by CALTREN

V2V protocols and the Cloud

V2V based traffic control essential for stability
Simulation results are backed up by experiments

- **VOLVO Platooning**
- **Luxemburg preliminary live DRIVE experiments**

However, protocol consistency and careful coordination necessary to manage complex traffic situations:

- **Platooning**
- **Shock Waves**

Advanced V2V Protocols (CACC and DRIVE) will be implemented in the Vehicle Cloud

The Cloud implementation will assure consistency across Automakers

ITS: interaction of Clouds

- Safe Navigation
- Content Download/Upload
- Sensor Data gathering

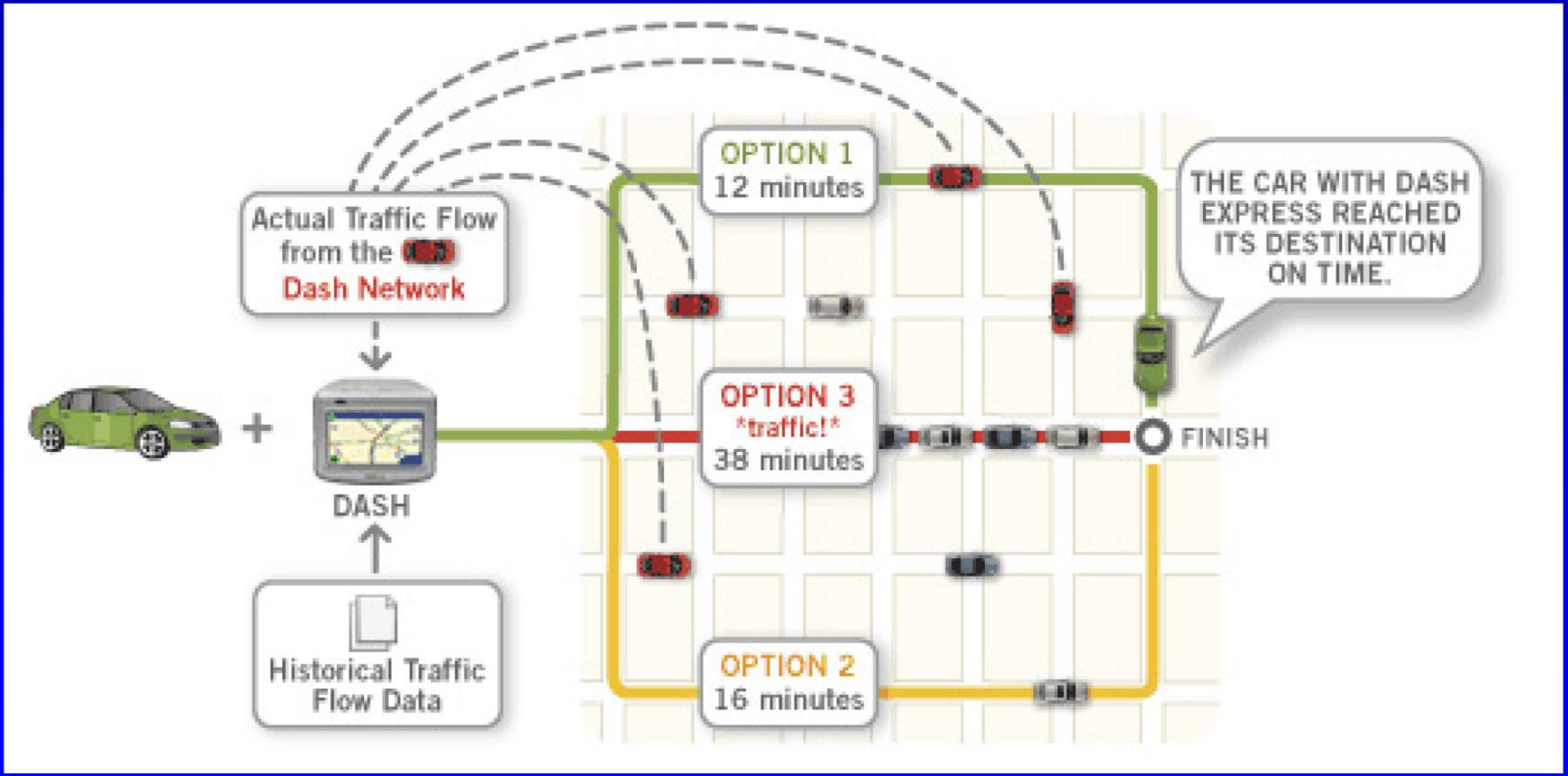
=> Intelligent Transport

- Defense from cyber attacks

Motivation: We are currently funded by NSF to solve the vehicle congestion and pollution problem with “Intelligent traffic engineering”

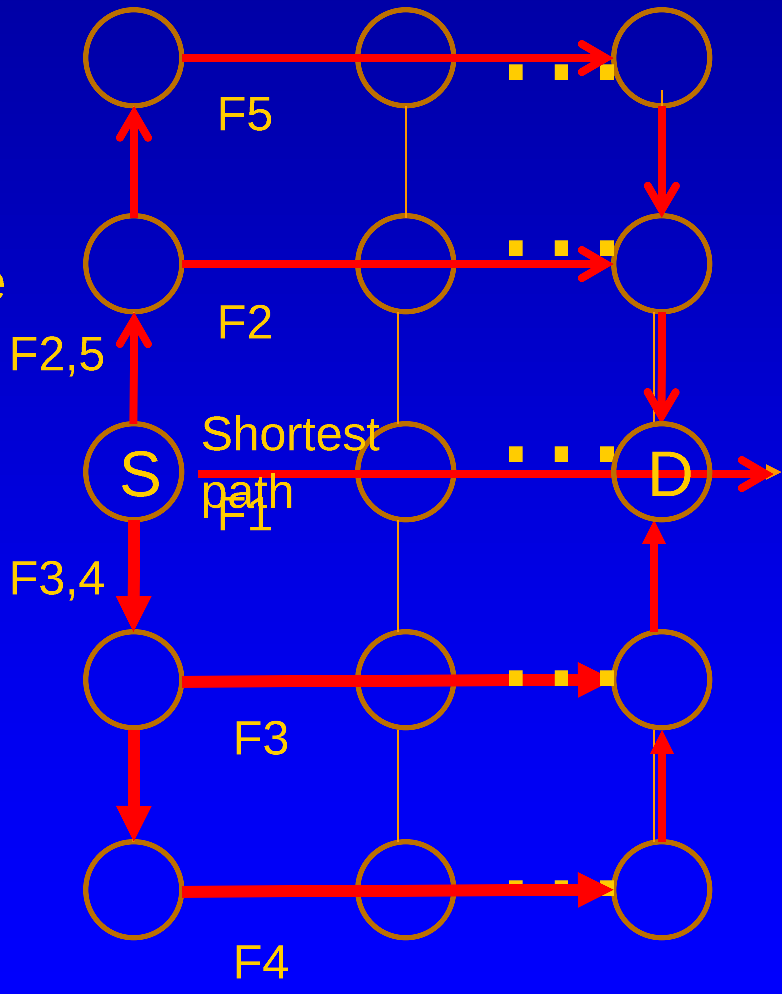
Intelligent navigation

- Dash Express periodically sends GPS + Time to Server
- Still runs into traffic fluctuation problems (ie route flapping)



NAVOPT – Centralized Navigator Server (in Cloud) Route Optimization

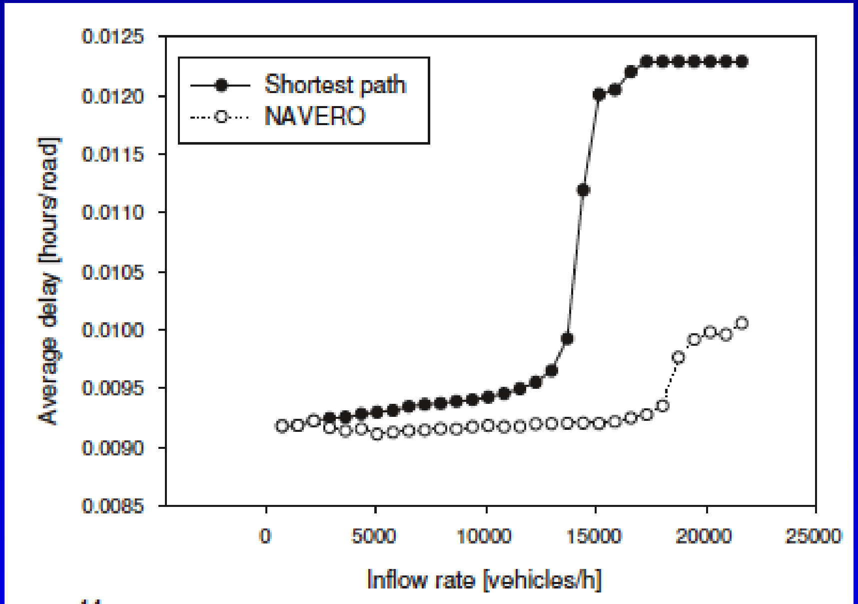
- **On Board Navigator**
  - Interacts with the Server
  - Periodically transmits GPS and route
  - Receives route instructions

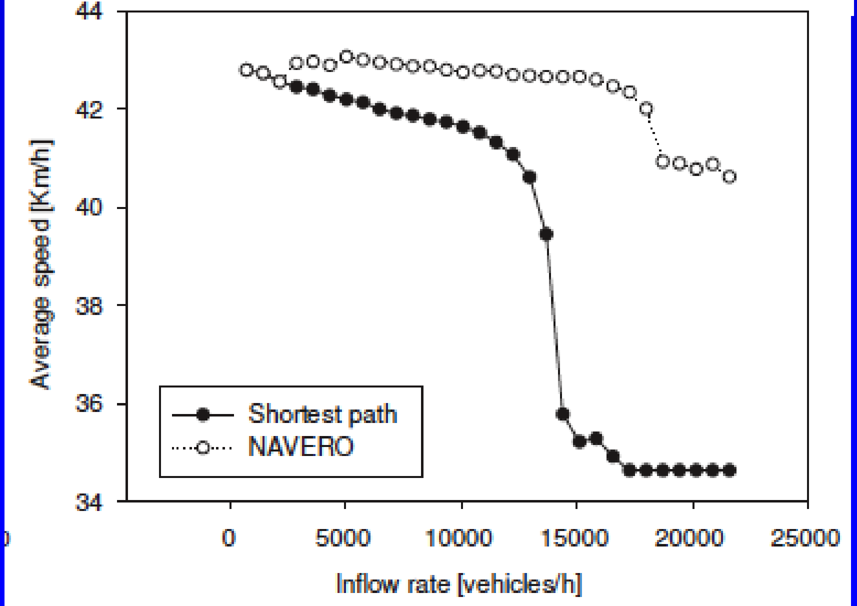


- **Manhattan grid (10x10)**
  - 5 routes (F1~ F5) from source to destination
  - Link capacity: 14,925 [vehicles/h]

Sumo simulation results

- **Sumo-0.12**
  - 10 X10 grid
  - Road segment: 400m
  - Length of vehicle: 4m
  - Max speed limit: 60Km/h
- **Average delay**
  - Delay increases drastically around 15000 rate [veh/h] in case of shortest path
  - In NAVOPT, delay slightly increases around 20000





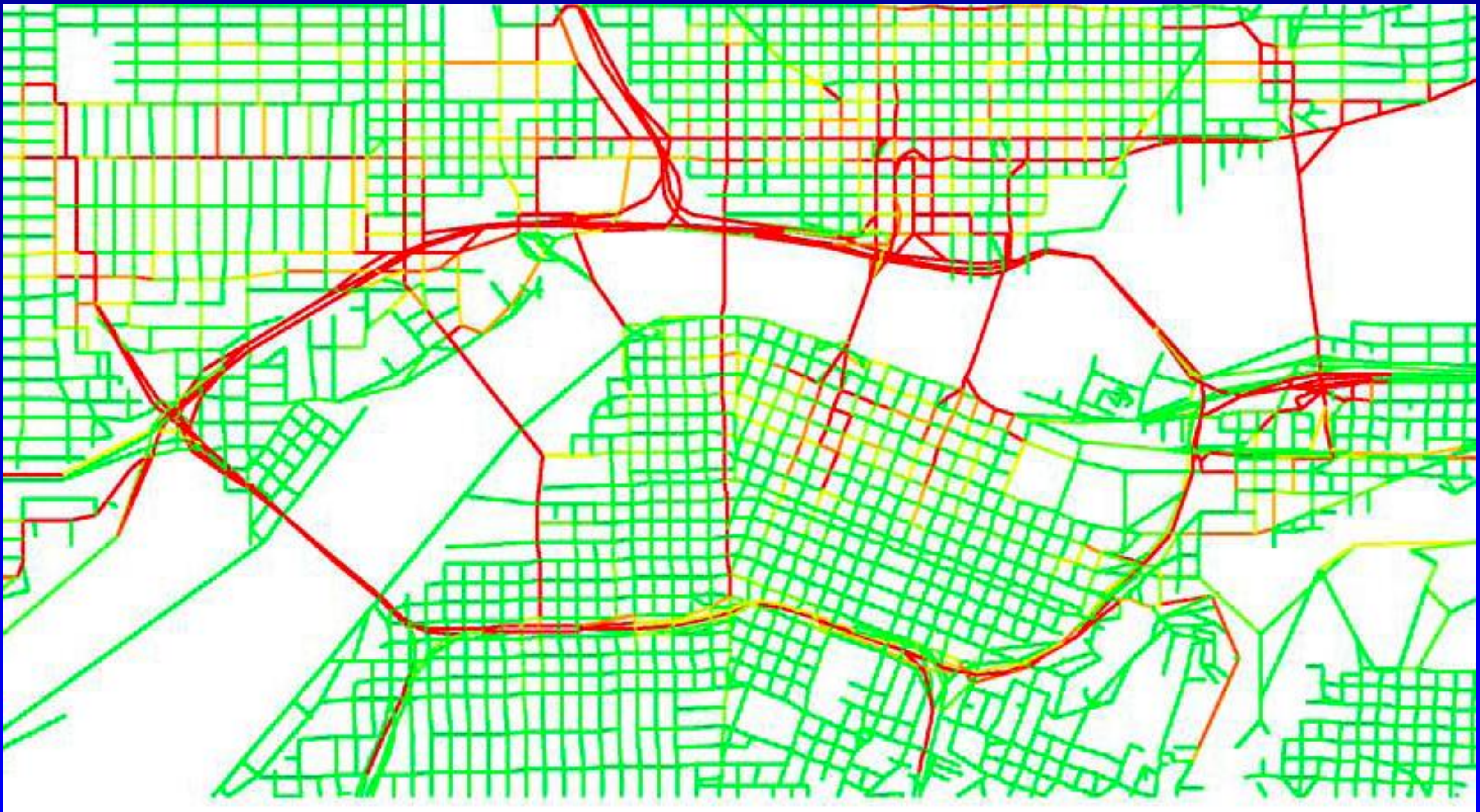
Distributed traffic management

- **Centralized traffic management is Internet Cloud based**
- **It cannot react promptly to local traffic perturbations**
  - A doubled parked truck in the next block; a traffic accident; a sudden surge of traffic
  - Internet based Navigator Server cannot micro-manage traffic for scalability reasons
- **Enter distributed, v-cloud based traffic mgmt**
  - Distributed approach a good complement of centralized supervision
  - *“On the Effectiveness of an Opportunistic Traffic Management System for Vehicular Networks”, Leontiadis et al, IEEE Trans on ITS Dec 2011*

CATE: Comp Assisted Travl Environment

- **Vehicles crowd source traffic information and build traffic load data base:**
  - 1) estimate traffic from own travel time;
  - 2) share it with neighboring vehicles (in an ad hoc manner); and
  - 3) dynamically recompute the best route to destination
- **The study was done by simulation:**
  - QUALNET and MobiDense (mobility trace generator)
  - Case Study: Traffic pattern for Portland

Traffic loading w/o CATE



(a)

Green no congest   Yellow moderate   Red heavy congest

Traffic loading with CATE

(b)

Green no congest   Yellow moderate   Red heavy congest

Integrating Centralized and Distributed traffic management

- **Central Navigator Server in the Amazon cloud:**
  - Provides MACRO traffic instructions
  - Is aware of user destinations
  - Can perform ECO-Routing (accounting for pollution)
  - Interacts with City Planners (eg Green waves, Congest Fees)
- **Distributed traffic mngt in the Vehicular Cloud:**
  - Can handle sudden traffic jams, accidents, other anomalies
  - Provides “miopic” traffic redirections w/o preempting Server
  - Can be a safety net when infrastructure fails
- **Amazon Cloud + Vehicle Cloud :**
  - Improves scalability, reaction time, robustness to disasters

Interaction of Three Clouds

After major road chemical spill:

•V2V Cloud alerts vehicles of peril - instantaneous

•Edge Cloud determines which roads, schools to close - seconds

•Internet Cloud computes plume dynamics based on wind etc - minutes

Potential V2V Problems: BOT Attacks

- **BOTNET type attacks:**
  - A malicious organization can penetrate (via entertainment system?) and compromise several cars – ie turn them into BOTS

The compromised cars send false (but fully “authenticated”) advertisements and force the legitimate traffic to go into a trap, causing traffic jams

BOT Cars Attack to Distrib. traffic mngt

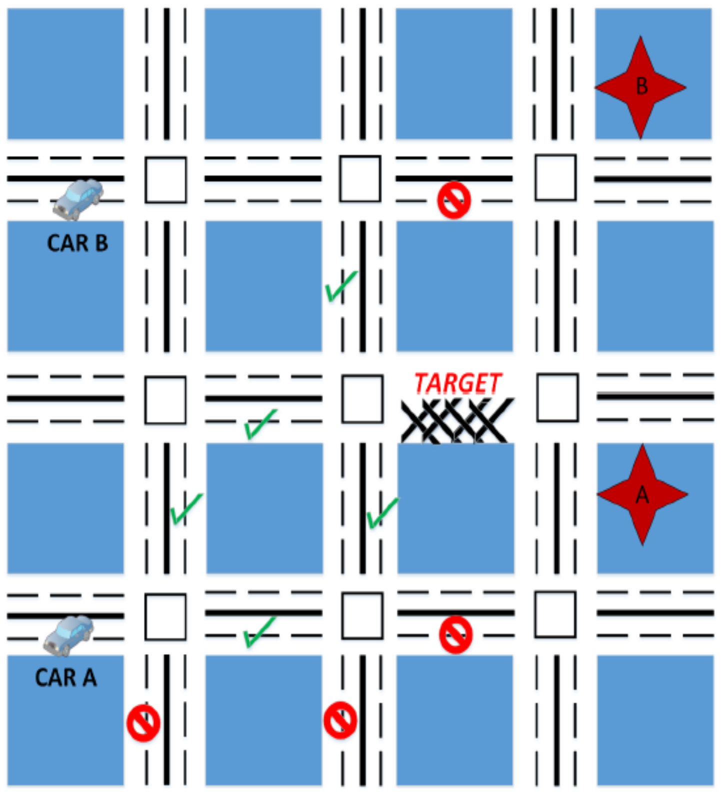


Figure 2: Malicious advertisements for the cars that are considering taking the targeted road

The BOT Cars lure Car A and B intro the target (a TRAP)

They advertise heavy loads on all routes (marked by red circles) except for routes to Target

Effect of BOT attack on speed

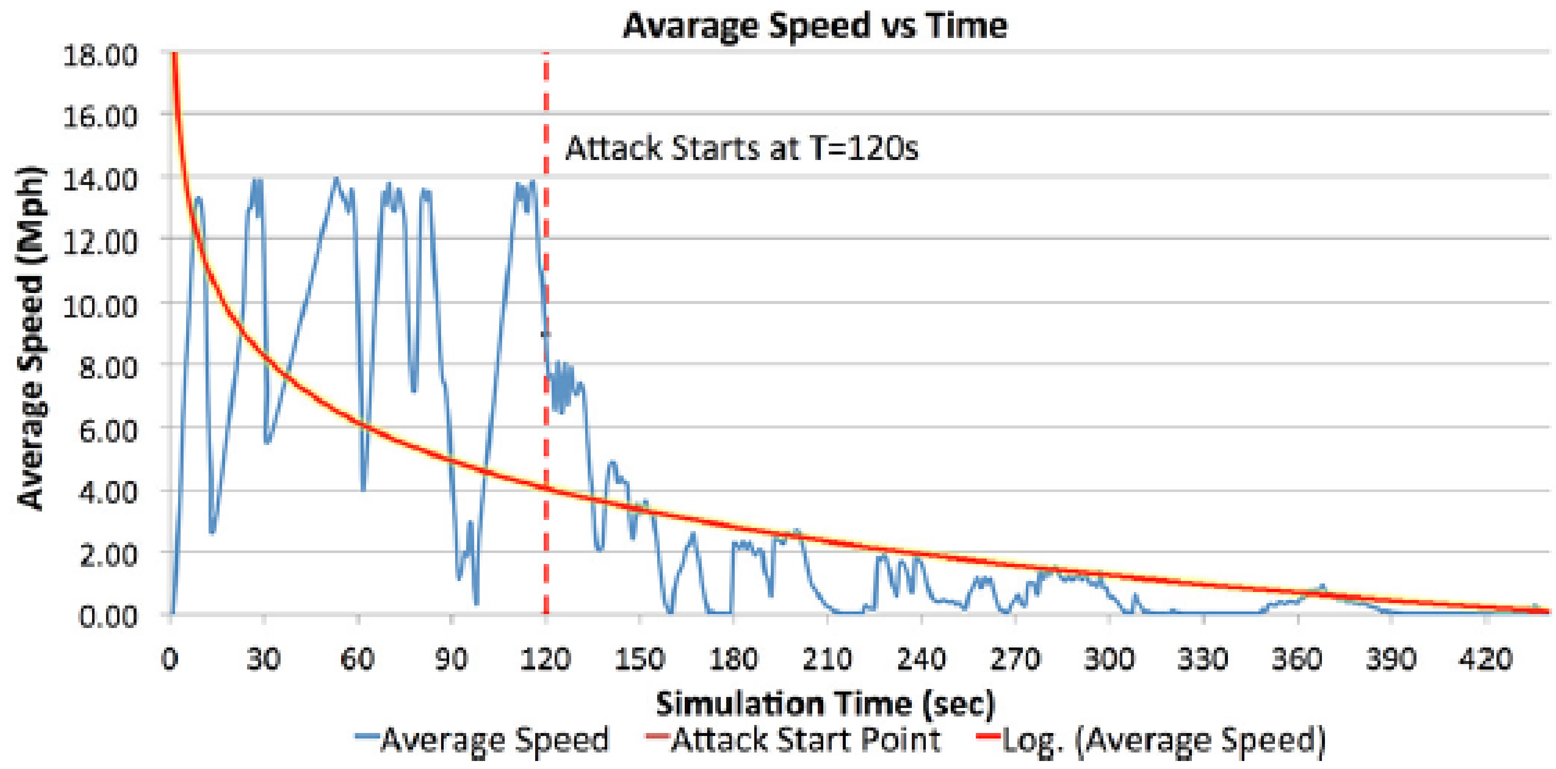


Figure 8: Average speed graph where attack starts 120 seconds after the beginning of the experiment

Defense from BOT Car attacks: use Edge Cloud

- **Recall:** Centralized Mngt Server (in Edge Cloud) carries out medium and long term route optimization

- **Defense:** Edgs Cloud detects inconsistency between road segment congestion and surrounding areas light loading. It wakes up drivers.

Vehicle Cloud – The Vision

- **A Platform with Basic Services and APIs**
  - Applications built on top of common building blocks
  - Various (5G) physical radio layers supported
- **Platform's "Narrow waist" – Network Layer**
  - Conventional Routing (eg, OLSR, GeoRouting, etc)
  - Named Routing (NDN, ICN)
  - Unicast. Multicast, DTN, (epidemic) dissemination
- **Basic Services**
  - Sensor Services: Unified sensor APIs; CAN bus sensors; sensor aggregation; Spectrum availability crowd sourcing;
  - Data Services: data mining; correlated searches
  - Security Services: privacy; security; DDoS protection
  - Social Network Services: Proximity enabled social networking on the mobile cloud
  - Virtualization Support: eg multi sensor virtual platform

In summary

- **IOV and Vehicle Cloud set the stage for future vehicular applications:**
  - IOV enables collection, uploading, dissemination of the DATA
  - Vehicular Cloud will assist in the deployment of Applications (standardization, privacy preservation, security)
  - Interaction between Vehicle, Edge and Internet Clouds
- **V2V is critical for several apps:**
  - Safe Navigation
  - intelligent transport
  - Surveillance
- **IOV + Vehicle Cloud next challenges**
  - Keep up with 5G
  - Protect from Attacks
  - Enhance Autonomous Driving (aged and impaired drivers, shared vehicle distribution, EV recharging, etc)

Thank You

Questions?