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

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Evolution of Urban Fleet of Vehicles

- From a collection of sensor platforms
  - Collect/deliver sensor data to drivers and Internet cloud.
- To the Internet of Vehicles (IOV)
  - Share sensor inputs to optimize local utility functions (e.g., autonomous driving).

- In this talk:
  - Identify unique challenges of IOV as opposed to conventional IOT models (say, Internet of Energy).
  - Specify Vehicular Cloud as a promising solution.
    - What leads to the cloud?
    - What are technical challenges?
    - What services the cloud can provide?

Comparison: 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

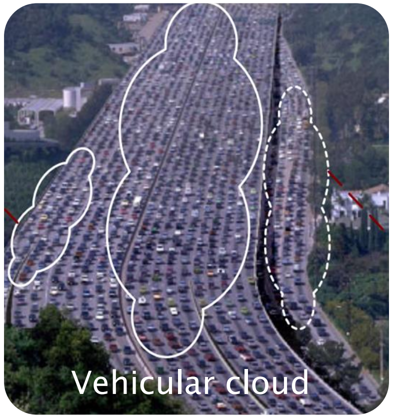
Mobility/V2V Communications Makes IOV Unique

- Smart Grid: Objects are hierarchically controlled.
  - This enormously helps scalability from room to building to city
- Vehicular Cloud: Vehicles cannot be hierarchically partitioned and controlled.
  - Mobility handling & real-time, low latency V2V requirements
    - Many platooning papers stress critical need of V2V.
  - But these are not critical concerns in IOE/m-Health IOT apps

Computing Models:

- Internet Cloud Computing (e.g., Amazon, Google)
  - Data center model
  - Immense computer, storage resources
  - Broadband connectivity
  - Services, virtualization, security
- Mobile Cloud Computing (traditional)
  - What most researchers mean:
    - Access to the Internet Cloud from mobiles
    - Tradeoffs between local and cloud computing (e.g., offloading)
- P2P Model: Mobile Computing Cloud
  - Mobile nodes increasingly powerful (storage, process, sensors)
  - Emerging distributed apps (e.g., localized sensing/computing)

Vehicular Cloud



Observed trends/characteristics:

1. Vehicles are powerful sensor platforms

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

2. Spectrum is scarce => Internet upload expensive

3. More local data must be processed on vehicles

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

    surveillance (video, mechanical, chemical sensors)

    environment mapping via "crowdsourcing"

    accident, crime witnessing (for forensic investigations, etc.)

⇒ Vehicular Computing Cloud

Data storage/processing on vehicles

Vehicular Cloud vs. Internet Cloud

- Both offer a significant pool of resources:
  - Computing, storage, communications

Differences:

- Main vehicle cloud asset (and limit): mobility
- Vehicle cloud *services* are location relevant
  - Data Sources: from drivers or environment
  - Services: to drivers or to community
- Vehicle cloud can be sparse, intermittent
- Vehicle cloud interacts with:
  - Internet cloud
  - Pedestrian/bicycle (smartphones) cloud
- Very different business model than Internet Cloud

Vehicle Cloud Challenges and Services

- Challenges
  - Security / Privacy
  - Congested wireless medium
  - Content dissemination/discovery
  - Internet Cloud vs. Local Vehicle Cloud
  - Fair sharing (e.g., medium access), incentives

- Common Cloud Services
  - Efficient handling of above challenges
  - Uniform solutions across heterogeneous apps and platforms

Vehicular Cloud

Vehicles in the same geographic domain form a P2P cloud to collaborate in some activity

Related work:

MobiCloud – *Dijian Huang*

MAUI – *MSR*

Auton Vehi Clouds – *S. Olariu*

IC Net On Wheels – *Fan Bai GM*

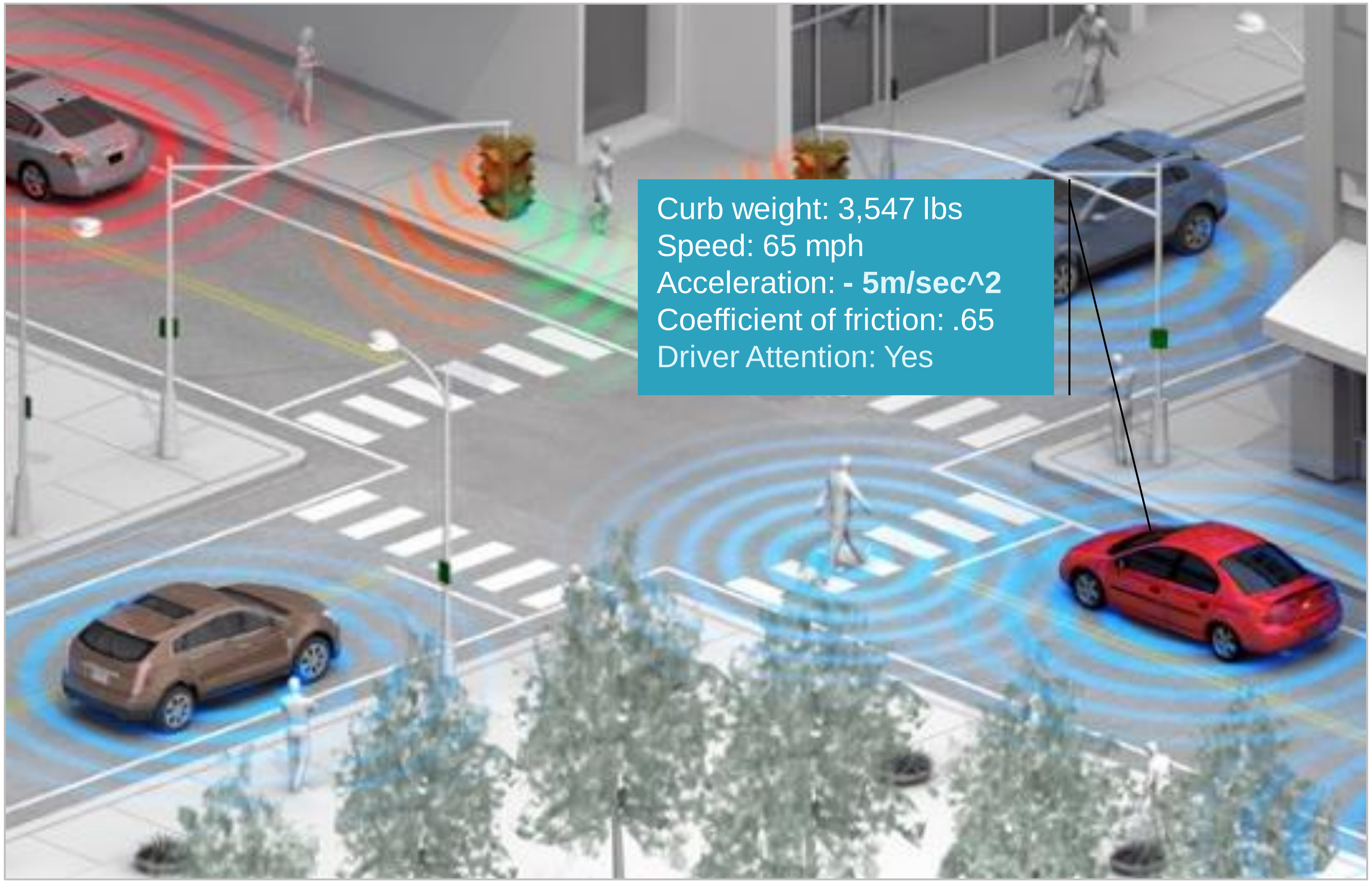
Emerging Vehicle Applications

- Safe navigation
- Location-relevant content distribution
- Urban sensing
- Efficient, intelligent, clean transport

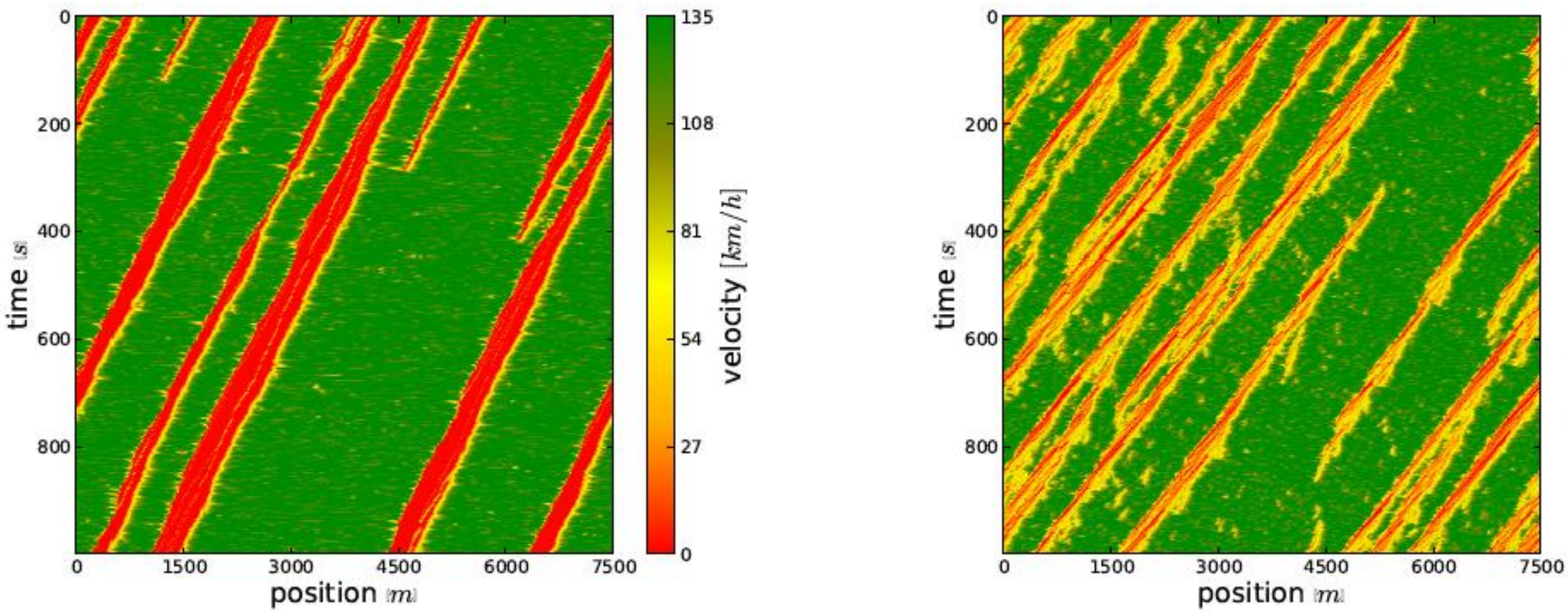
Safe Navigation

- Forward Collision Warning, Intersection Collision Warning
- Platooning (e.g., trucks)
- Advisories to other vehicles about road perils
  - "Ice on bridge", "Congestion ahead",....
- Autonomous driving

V2V Communications for Safe Driving



V2V and cruise control to avoid Shockwave formations



(a) VDR model

(b) PVS protocol

VDR = Velocity Dependent Randomization: *normal drive*

PVS = Partial Velocity Synchronization: *advanced cruise control*

A Study on Highway Traffic Flow Optimization using Partial Velocity Synchronization, Markus Forster, Raphael Frank, ThomasEngel, 2013

V2V for Platooning

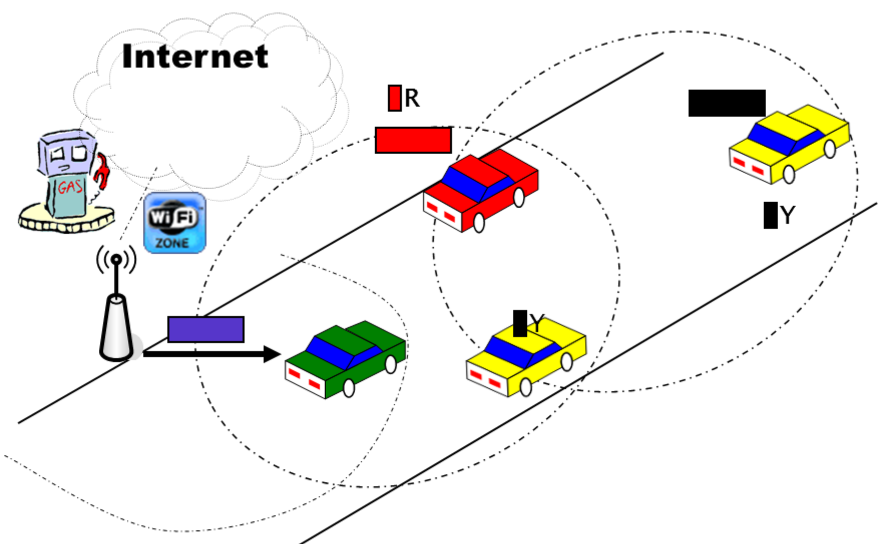
Study will offer insight into autonomous vehicle grids

Autonomous Vehicle Control

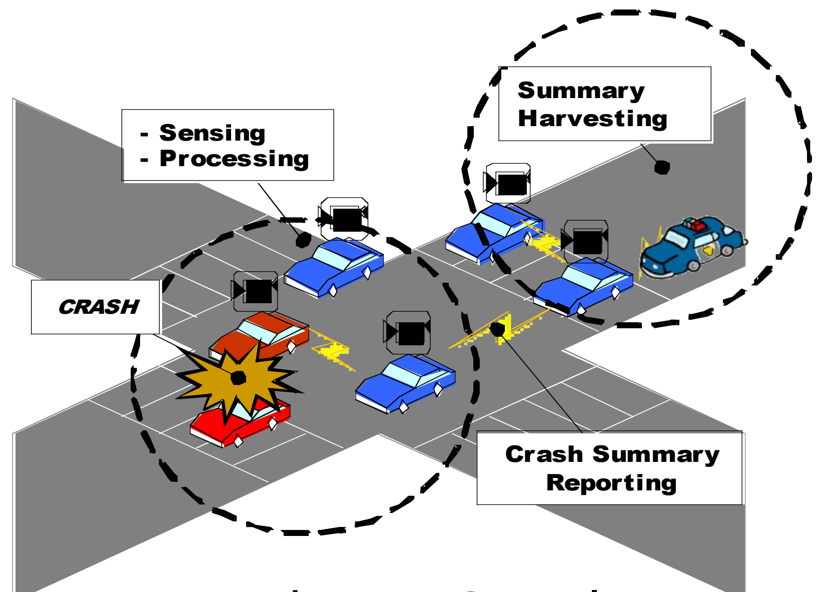
V2V more critical as autonomous car penetration increases

V2V for Location Relevant Content Delivery

- Traffic information
- Local attractions, advertisements
- Tourist information
- Accidents, crimes



CarTorrent



MobEyes, CarTel

Information Centric Networking for IOV

Ad-hoc net use cases:

- Rural and emergency scenarios
- Tactical battlefield
- Autonomous driving, shopping mall crowdsourcing, etc.

Common characteristics:

- Info centric, interm. connected, fast deployment, opportunistic routing and caching **based on context**

Info-centric Context-Aware Ad-hoc Net (ICAN)

- Extends and integrates *ICN, DTN, and opportunistic routing and caching* in one network architecture

ICAN Requirements

- Push- and pull-based application support
  - Must **push** to cars info of imminent danger
- Context-aware operations
  - Select routing and caching algorithms based on network/app **context**
- Fast deployment/reconfiguration

Network Entity Representation

- Data, node, and geo-location are all *addressable* network entities/objects; representation = address

1. **Data**: assume ICN hierarchical naming [1]
   - Format: ***application_id/data_object_id/chunk_id***
2. **Node**: unique node identifier
   - IP or MAC addresses
3. **Geo-location**: to support unicast/geocast applications
   - GPS coordinates
   - GPS coordinate + diameter

[1] Jacobson, Van, et al. "Networking named content." *Proceedings of the 5th international conference on Emerging networking experiments and technologies*. ACM, 2009.

Context

- From the representation, ICAN extracts the **context** of each entity and of associated packets/chunks
- Two types of context:
  - **Application related** (e.g., real time, private/public)
  - **Network condition related** (e.g., congestion, connectivity)
- From context, ICAN determines suitable **processing and forwarding policies** (e.g., push, dissemination, shortest path)

Context: Application

- Context: metadata associated with application or data-object

Meta-data Format

Attribute	Required	Value	Default Value
Content type	Yes	Offline/Real-time	Offline
Effective Time	Yes	[0 ms,∞]	∞
Publicity	Yes	Public/Private	Private
Popularity	No	High/Medium/Low	N/A
Max delay	No	[0 ms,∞]	N/A

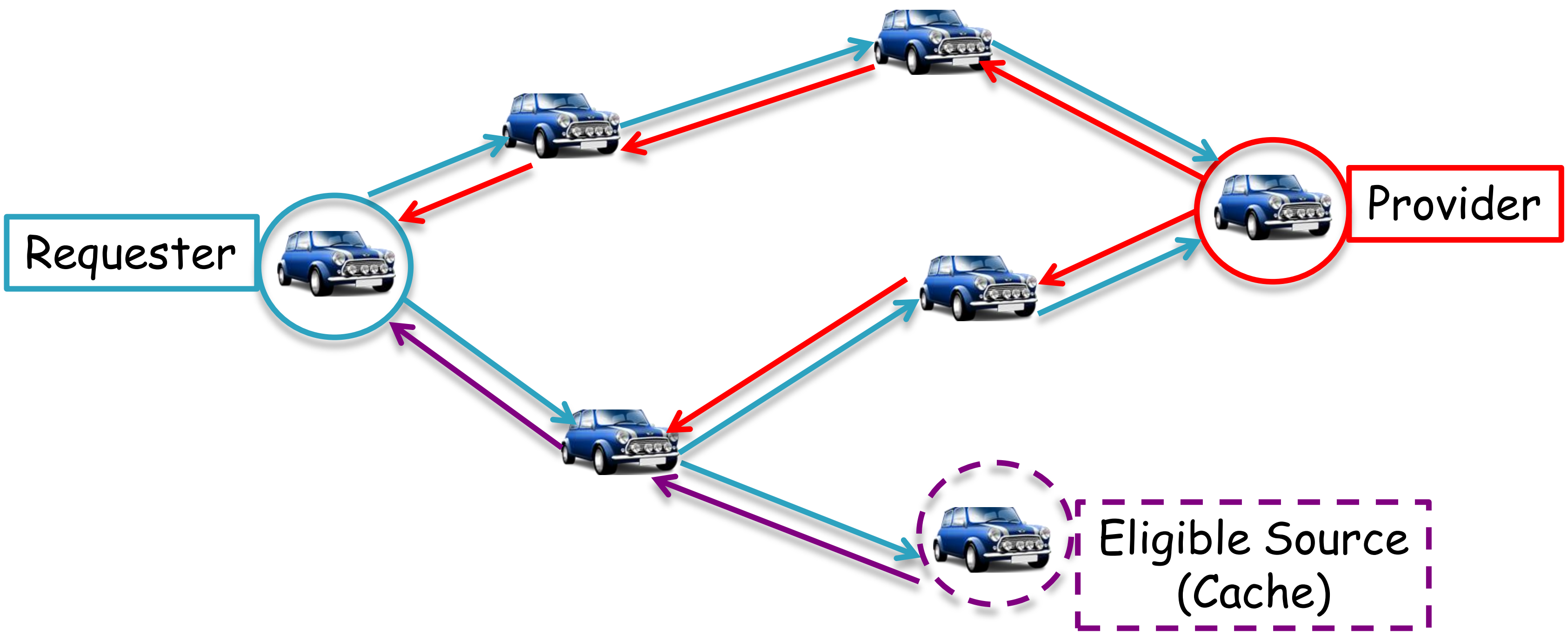
Examples

Application or Data object	Content type	Effect. time	Publi-city	Popu-larity	Max delay
Facebook	Offline	∞	Private	N/A	N/A
Car-A/break-alert	Real-time	1 min	Public	High	2ms
Map/Westwood-blvd	Offline	∞	Public	High	N/A
Traffic/Westwood-blvd	Real-time	15 mins	Public	High	N/A
NYTimes/homepage	Offline	4hrs	Public	Medium	N/A

Context: Network Conditions

- Associated with Node Metadata
- Locally maintained and generated by nodes
  - Location: GPS coordinates
  - Neighbor list
    - Maintained by overhearing the ongoing traffic
  - Out-of-contact node list
    - Implicitly detected by observing the retransmission failures towards known destinations
- Nodes can:
  - Retrieve app and net metadata from data chunks
  - Explicitly request metadata

On-Demand Metadata Dissemination



Exploration Interest

Exploration reply = **Source list (ID+location)** + **metadata**

The metadata is propagated to many relays.

Conclusions

- Vehicular Cloud: a model for the systematic implementation of services in the vehicular grid
  - Services to support vehicle app (e.g., safe navigation, intelligent transport, etc.)
  - Services to support external apps (e.g., surveillance, forensic investigation, etc.)
- Recent events favor the development of V2V and thus of Vehicular Cloud services
  - USDOT V2V endorsement
  - The emergence of autonomous vehicles (Google Car etc.)
- Case study: Content dissem/retrieval service
  - ICAN = ICN + context (app. and network) awareness

Conclusions (cont)

- As vehicles become more autonomous, the need for V2V communications will increase
- The wireless radio technology landscape will change dynamically given spectrum scarcity and value
- The future autonomous vehicle must be radio and spectrum “agile” in order to deliver safety, efficiency and comfort as promised
- To support this, the Vehicle Cloud will offer (via crowd sourcing) spectrum awareness service