V-NDN: Vehicular Named Data Networks

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Collaborative Work with:

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Outline

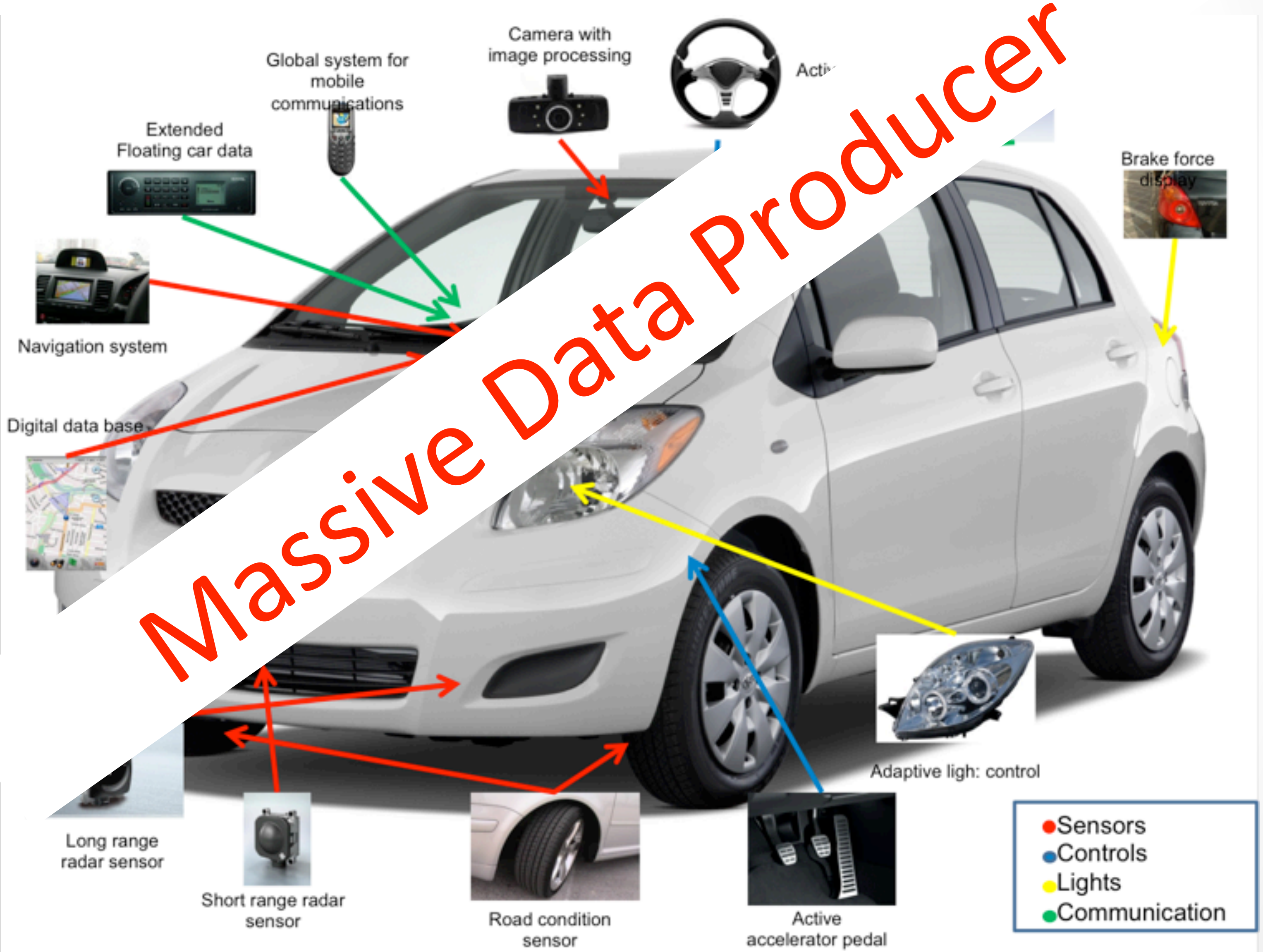
- **VANET's 101**
  - New Roles for vehicles
  - VANET's Communication Paradigm
  - Propagation & Mobility Effects
  - Why IP is not enough
- **VNDN**
  - Application Scenarios
  - VNDN Architecture
  - Prototype and Evaluation
  - First Code Release and Integration
  - Future Work

… Cars …

- **They are present in large numbers**
  - China and India being the largest growing population of Cars
  - With a penetration rate of about 70% in most developed countries.
- **Have virtually no energy constrains**
  - When the engine is ON energy is produced by the alternator
  - When Parked energy can be harvested from the Battery (some energy issues here)
- **Can exploit mobility**
  - Principal duty of vehicles is transportation of goods and people. It is possible to see public vehicles as a mean to build an urban sensor netowrk.
- **Can carry relatively large loads**
  - Can be instrumented with sensors, communication devices and computing units.
  - Many Manufacturers are exploring connected vehicles to provide advanced services.

- **In essence can they are the ideal candidates as nodes of a wireless mobile network.**

… Cars …



Camera with image processing
Global system for mobile communications
Acti
Extended Floating car data
Brake force display
Navigation system
Digital data base
Massive Data Producer
Adaptive ligh: control
Long range radar sensor
Short range radar sensor
Road condition sensor
Active accelerator pedal
Sensors
Controls
Lights
Communication

New Vehicular Apps

- **Safe navigation:**
  - Vehicle & Vehicle, Vehicle & Roadway communications
    - This will be essential in autonomous driving
  - Forward Collision Warning, Blind Spot Warning, Intersection Collision Warning
  - In-Vehicle Advisories from CAN sensors
    - “Ice on bridge”, “Congestion ahead”,….
- **Entertainment**
  - Share location critical multimedia files
  - Exchange local ad information
  - Support passenger to passenger internet games
- **Smart City Applications**
  - Monitor Pollution and optimize traffic flow
  - Smart Navigation Services
  - Smart Grid nodes (with electric vehicles)
  - Urban Surveillance
- **Data Mules**
  - Vehicles can carry large amounts of data between points (i.e. large backups)

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Vehicular Paradigms

- **Vehicle to Vehicle (V2V): presents the challenges typical of an ad hoc network in addition to a very high speed mobility and an intermittent connectivity**
- **Vehicle to Infrastructure (V2I): Protocol design is challenged by intermittent connectivity and short communication windows.**
- **Opportunistic: V2V for a limited number of hops until is possible to connect to the Infrastructure.**
  - Note: infrastructure is also a neighbors' 3G.

Vanets in a Nutshell

- **Vehicular networks are opportunistic by design to cope with the effects of mobility** and **propagation**.
- **Mobility**: Causes disruption due to rapid changes in the underneath topology.
- **Propagation**: Disruptive multipath fading and Obstructions create frequently link disruptions

- In short a **dynamically partitioning** network, the ability tolerate disruption is essential in the application design as well as at the network layer.

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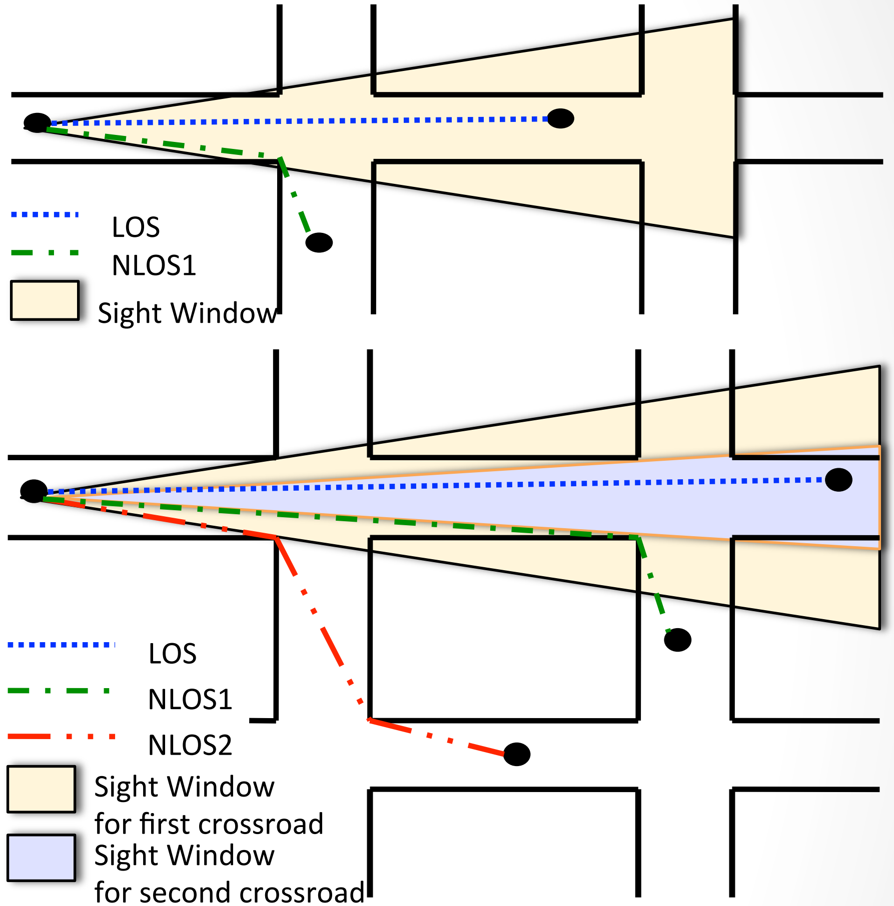
Propagation

- **Place vehicles on road segments (specialized reverse geocoding)**
- **Two vehicles:**
  - Same road segment: LOS
  - Adjacent road segment: either LOS or NLOS1
  - Connected road segment:
  - LOS, NLOS1 or NLOS2



LOS, NLOS1, NLOS2 attenuation formulae provided by:

Analytical formulae for path loss prediction in urban street grid microcellular environments,

Q Sun, SY Tan, KC Teh - IEEE Transactions on Vehicular Technology, 2005 - ieeexplore.ieee.org

Propagation: Example

- **Fixed Tx**
- **Mobile Rx**
  - Moves first from LOS to NLOS1then to NLOS2

Impossibile visualizzare l'immagine. La memoria del computer potrebbe essere insufficiente per aprire l'immagine oppure l'immagine potrebbe essere danneggiata. Riavviare il computer e aprire di nuovo il file. Se viene visualizzata di nuovo la x rossa, potrebbe essere necessario eliminare l'immagine e inserirla di nuovo.

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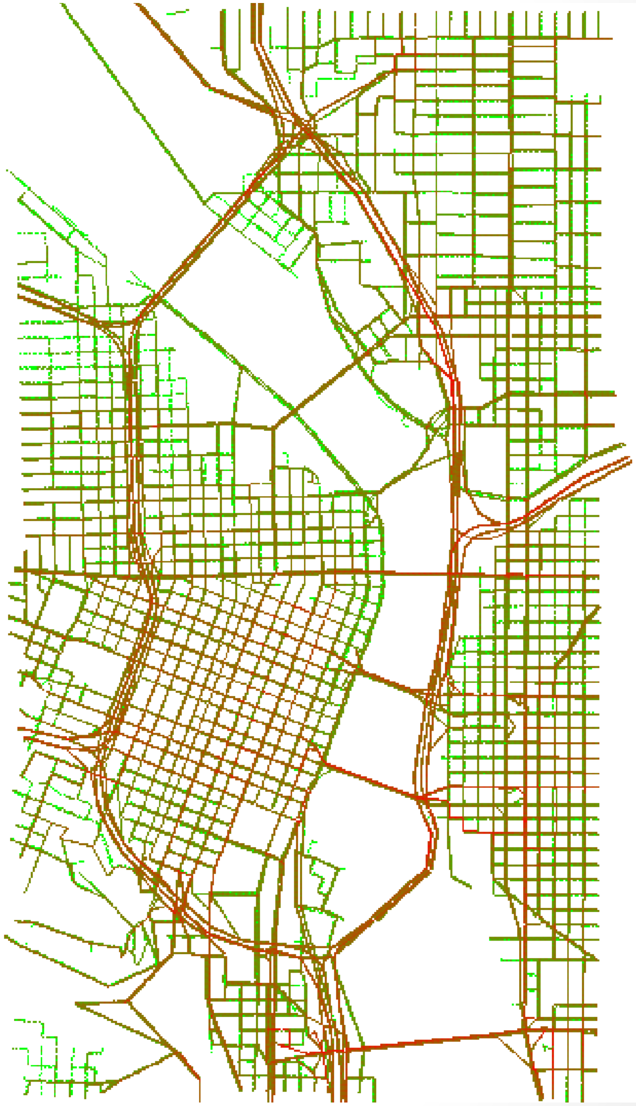
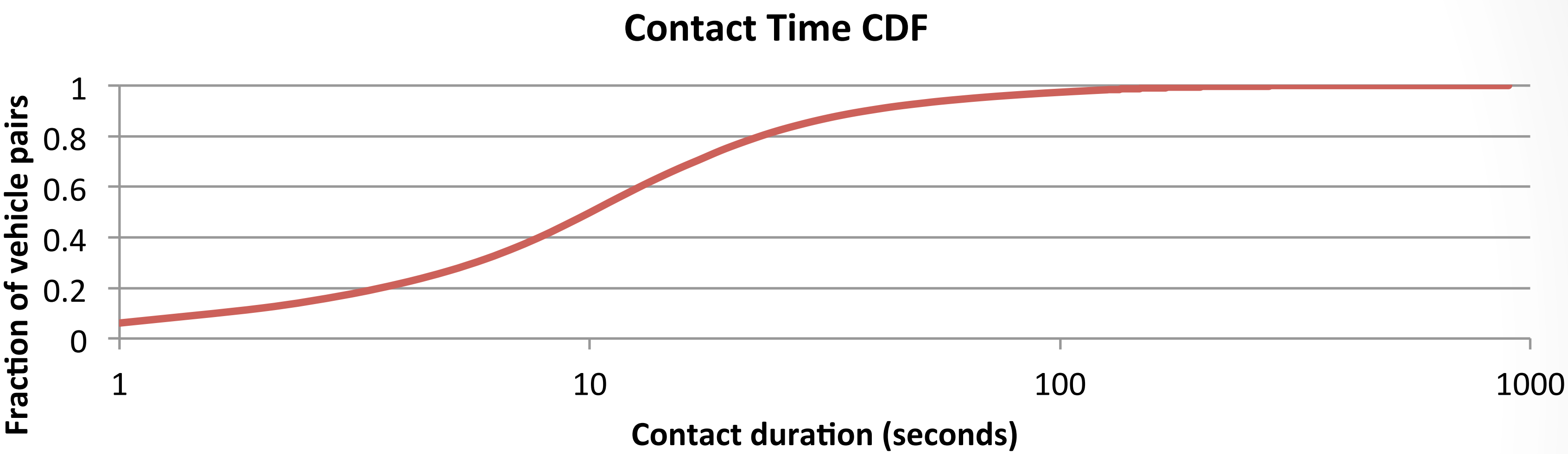
E. Giordano, R. Frank, G. Pau, and M. Gerla, "Corner: a step towards realistic simulations for vanet," VANET 2010.

Vanets: Mobility

- **Portland Traces:**
  - Non-public mobility trace provided by Los Alamos National Laboratories
  - Generated Using TRANSIMS, based on mobility surveys
  - 15 minutes trace of a 3x7 Km area of the city of Portland (OR) representing a week-day from 8.00 to 8.15 am
  - The area contains urban and freeway traffic as well.
  - Contains 16.528 unique vehicles



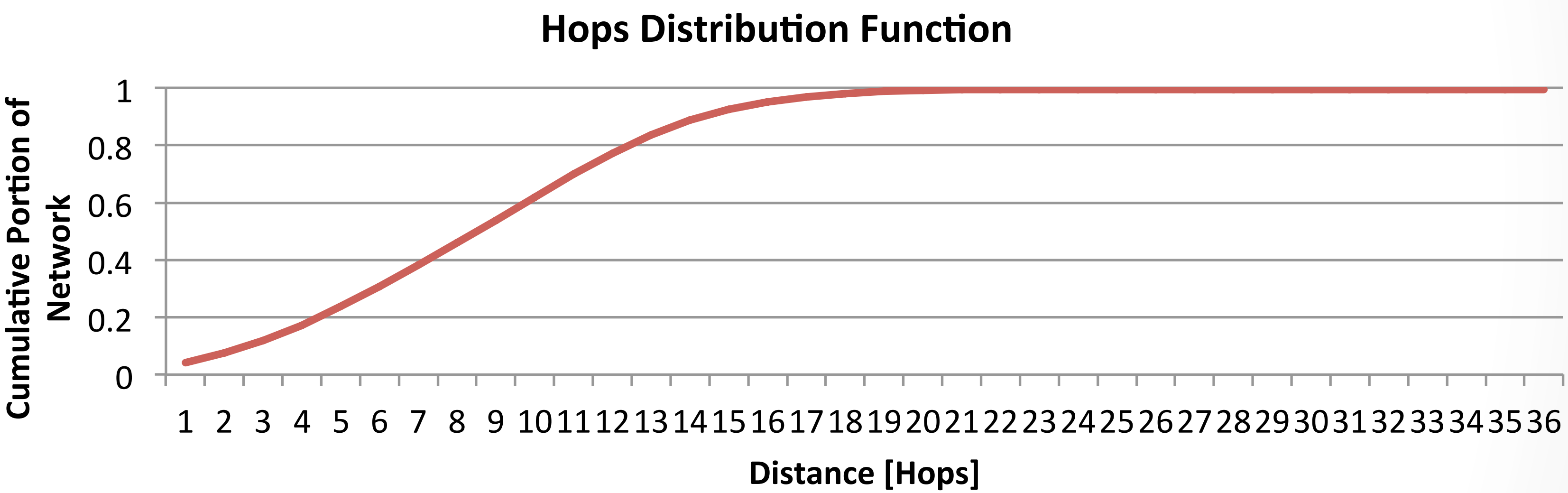
Mobility: Contact Time



- **The median contact time is 10 seconds**
- **The average contact time is 14s**
  The variance is 20.7

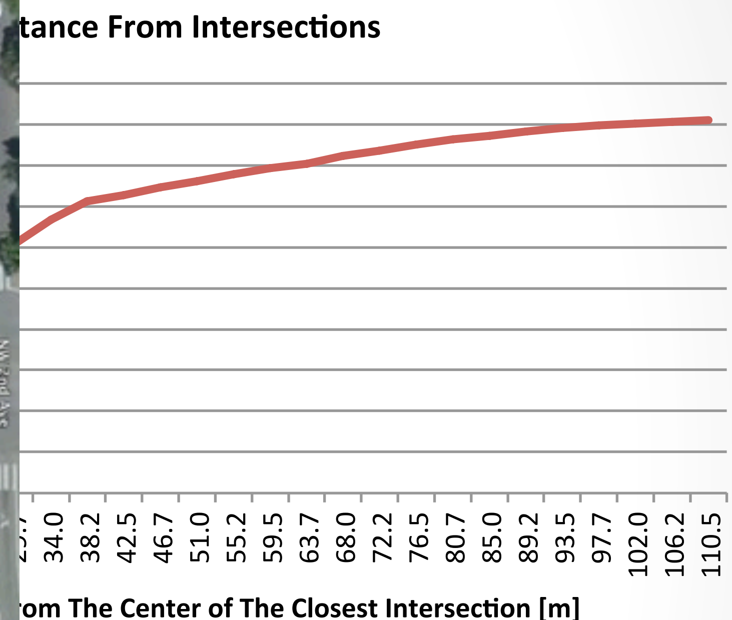
Network Topology

- Assuming: Penetration=1 (every car on the road is instrumented)
- Connectivity Index (CI): Average portion on network reachable from any node
- CI = 0.96; The network is almost fully connected



- **The median hop distance is 9 hops**
- **There are paths 30 hops long.**

But...Where are the Cars?



vehicles is within 25
an intersection

A. Rowstron and G. Pau —Characteristics of a Vehicular Network,
UCLA Computer Science Department Technical Report N. TR#090017, Summer, 2009.

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Why not IP?

- **Vehicle-to-vehicle communication**
  - Before retrieving data, vehicles have to know who has the data
  - Very hard in mobile dynamically partitioning and fully distributed environments
  - End-to-end communication prohibits the direct reply of intermediate vehicles, which are also producers and may also have the desired data
- **Multiple interfaces (Multi Homing)**
  - LTE and WIFI are assigned different IPs, so they are separate connections
  - Hard to utilize multiple interfaces simultaneously

Why NDN?

Many years of research in VANETs and DTNs are still far from completion.
Why?

IP puts addresses at the center of its communication model, thus becoming strictly connected with network topology.

This does not work well in VANETs, dynamic partitioning topologies.

By naming data, rather than hosts, *NDN* easily overcomes this limitation.

Data exists in the ***absence*** *of connectivity* and can be exchanged over any physical channel once it comes into existence.

We designed and implemented the first prototype of *V-NDN* that leverages NDN strengths and can fully utilize several wireless technologies at the same time, e.g. WiFi (both managed and ad-hoc), WiMax, 3G.

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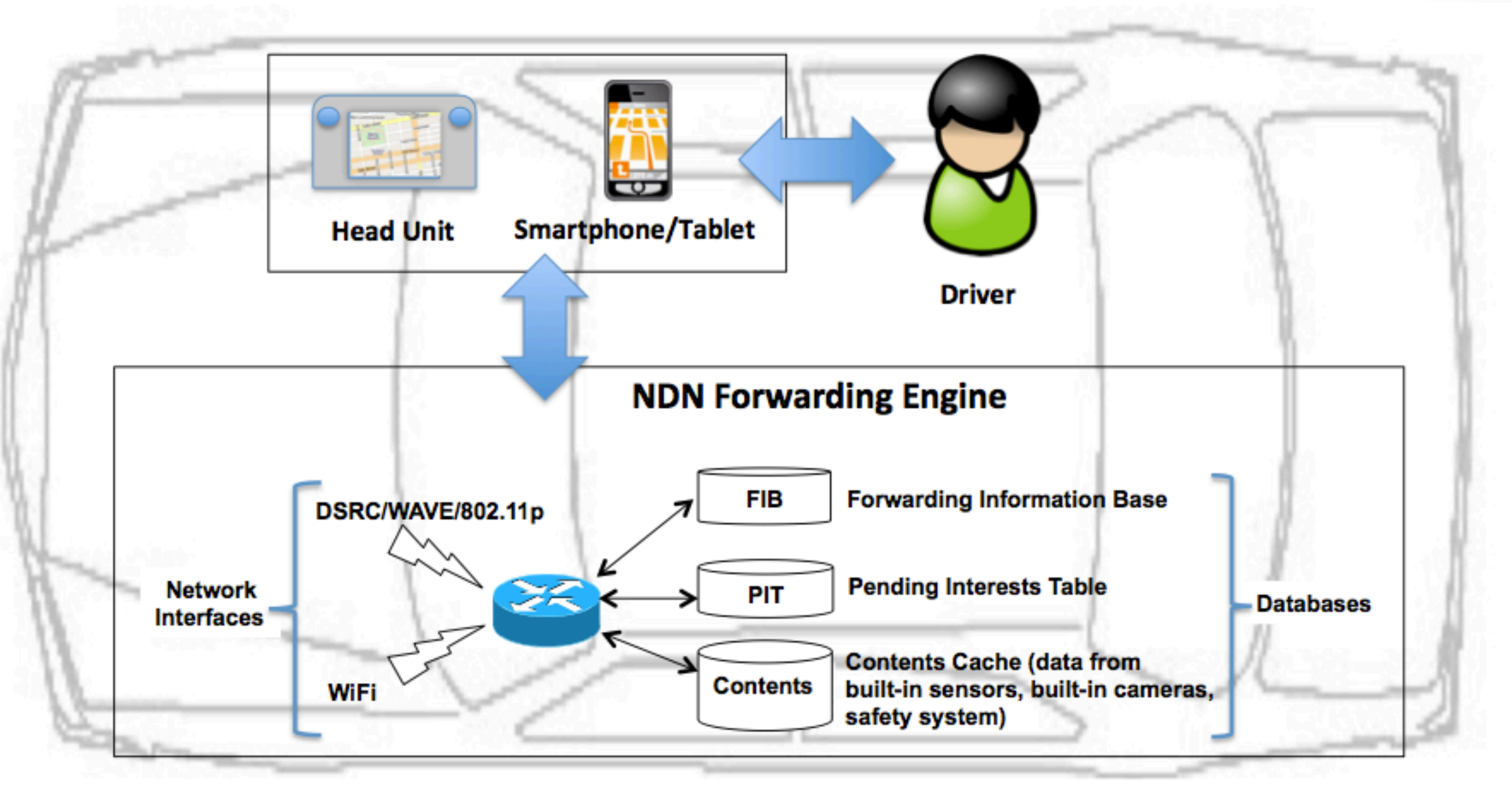
An NDN enabled Car

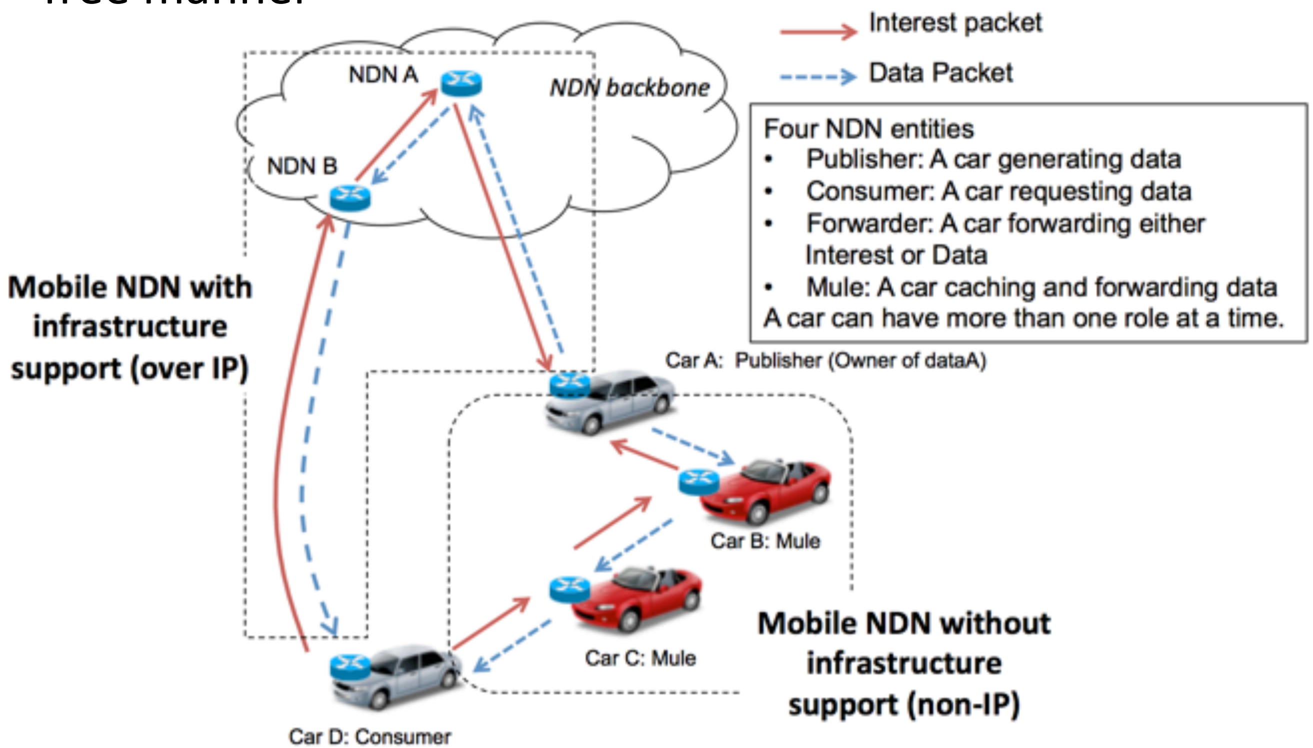


Borrowed from Ryuji Wakikawa

Application Scenarios

Applying NDN to vehicle networking

- **Creating a *single framework* that enables vehicles**
  - to fully utilize any and all available physical communication channels
  - to communicate with each other in a completely infrastructure-free manner



NDN on Vanet

- **Mobility**
  - Dynamic and fast topology changes
- **Capacity**
  - No concern with power, storage (or even processing)
- **OBJECTIVE**
  - Develop VANET NDN implementation that is compatible with CCNX on the wire but accounts for the specificity of the Vanet requirements

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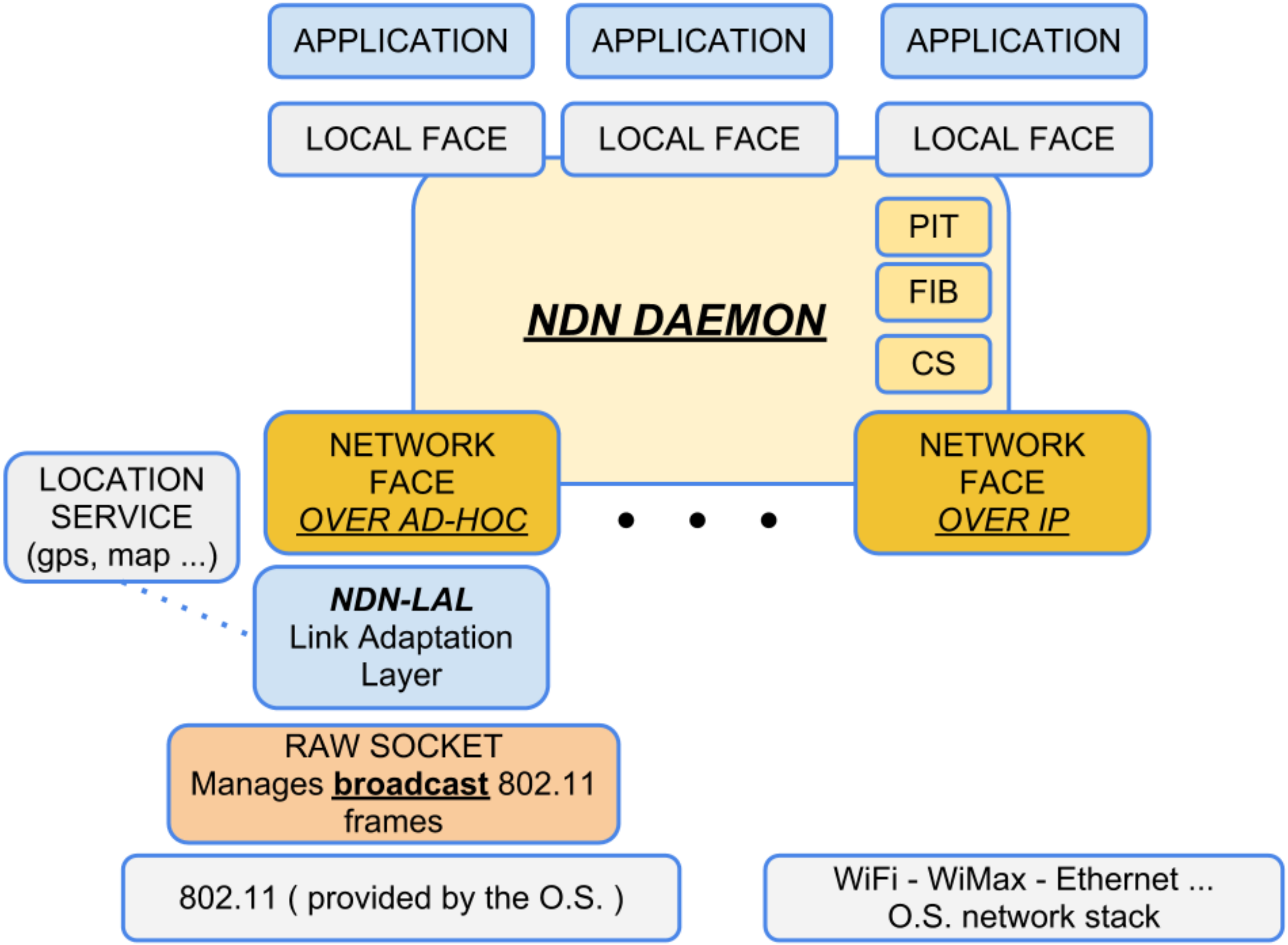
Architecture



NDND for VANETs

- **Wire Format: Same as CCNX**
- **Forwarding**
  - Prefix match as in the wired NDN design.
  - Allow packets to go out on the **originating interfaces**
- **Pit**
  - **Current**: Behaves as regular PIT
  - **Future**: Interests expire by deadlines, **NOT** consumed by receiving a single piece of relative content (i.e. receiving data from multiple sources).
    - _A typical case are the traffic-related information or warning situations.
    - i.e. I may send an interest for emergency warnings and I want to get all of them.

NDND for VANETs

- **FIB**
  - The highly dynamic underlying topology requires the FIB to be populated piggybacking on the traffic rather than relaying on a routing protocol in wired NDN
  - Naming data with geographic information to guide the forwarding

- **Data Caching**
  - Caching unsolicited data for potential future use (by self or requested by other cars)
  - Need to invest new cache management schemes to fit Vanet environment

NDN V2V Link Adaptation Layer

- **Mobility changes the underneath topology**
  - ALL transmissions are made in broadcast
    - **Current** WiFi protocol is designed for point-to-point, **no L2 feedback for broadcast**.
  - To limit flooding, Only the **<u>furthest</u>** away node from the last sender forwards the packet.
    - The mechanism uses distance info from GPS coordinates plus small randomized waiting.
  - Hearing a packet's further forwarding is used as implicit-ack
    - If the implicit ack is not over-eared by the transmitter, the packet is quickly retransmitted (up to 7 times).
    - Using simulation to understand the trade-offs on the number of retransmissions and timing.

NDN V2I Network Face

- **NDN traffic is tunneled on IP/UDP to reach an NDN node behind the AP.**
  - Not the best approach but the feasible one for 3G-Like connectivity where very limited control is allowed.
  - In this case the behavior is very similar to CCNX, basically the wireless access is treated as a pipe with not much intelligence.
  - We have no control on any of the link parameters.

NDN Benefits for VANETs

- **Multi Homing**
  - NDN **naturally** enables multi-homing all interfaces can, and will be, used at the same time as needed to fetch the content.
    - Having the focus on the contents rather than the connection enables multi-homing at virtually no overhead
- **Opportunistic Networking**
  - VNDN enables nodes to perform communications in Ad Hoc (v2v), Infrastructure mode (v2I), and DTN (literally carrying the data) all at once, no modification in the protocol set or architecture are required.
- **Cars Can play several roles:**
  - Data producer/consumer
    - Applications running within vehicles will produce and consume data.
  - Forwarder/carrier
    - Thanks to NDN network layer abstraction vehicles will be able to forward data even for applications they do not have.
  - All this will happen seamlessly

Role of Naming

An example to follow

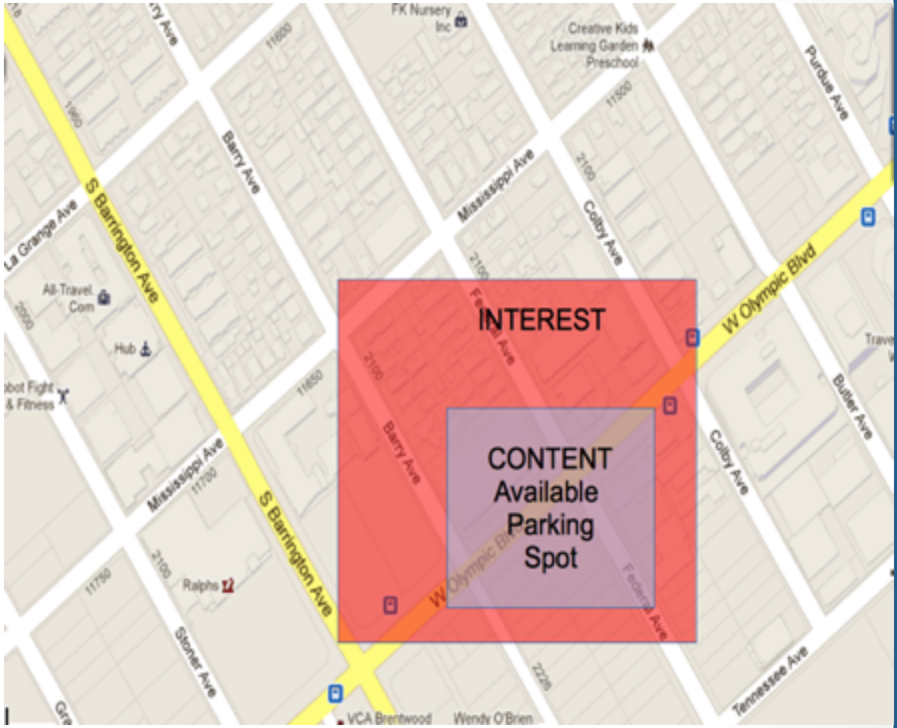
Applications will Drive the naming

- **Typical Vehicular Applications**
  - Finding Parking Information
  - Finding Traffic Information
  - Content Distribution
  - …
  -

Naming

- An interest concerning the red area should be satisfied by a content valid in a subset of that area (blue square).

- A key component of the solution is coming up with a naming scheme that would easily allow to express the concept of areas and sub-areas without requiring the NDN daemon to know anything about name semantics.



Encoding geographical information in the name

- **We can express a geographic area using a hierarchy of components:**

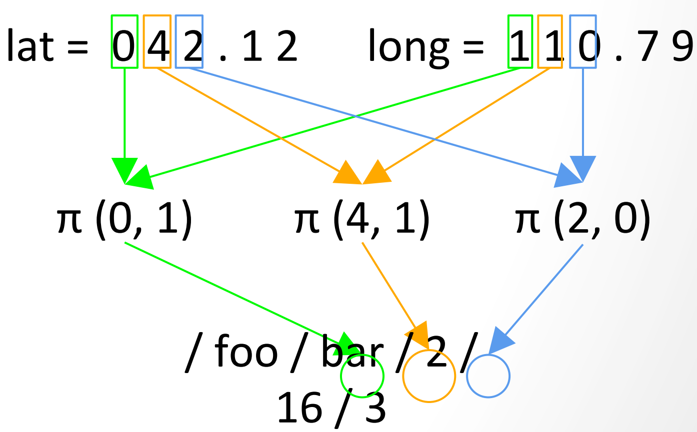
- **/application-name/coordinates that specify a 1 mile area/coordinates that specify a 0.5 miles area/coordinates that specify a 0.1 miles area/... and so on...**

- **This Would allow to Exploit the Longest Prefix Matching for V2V forwarding**

Encoding geo info in the name

- **Apply a digit-wise pairing function to the GPS coordinates. For example, Cantor pairing function (which is also easily invertible)**
- http://en.wikipedia.org/wiki/Pairing_function

- **Allows to express an interest about a wider area just by dropping name components from right to left. This is equivalent to removing some digits of precision from the fractional part of both coordinates.**



Accuracy of geo-aware names

Accuracy versus decimal places

decimal places	degrees	N/S or E/W at equator	E/W at 23N/S	E/W at 45N/S	E/W at 67N/S
0	1.0	111.32 km	102.47 km	78.71 km	43.496 km
1	0.1	11.132 km	10.247 km	7.871 km	4.3496 km
2	0.01	1.1132 km	1.0247 km	.7871 km	.43496 km
3	0.001	111.32 m	102.47 m	78.71 m	43.496 m
4	0.0001	11.132 m	10.247 m	7.871 m	4.3496 m
5	0.00001	1.1132 m	1.0247 m	.7871 m	.43496 m
6	0.000001	111.32 mm	102.47 mm	78.71 mm	43.496 mm
7	0.0000001	11.132 mm	10.247 mm	7.871 mm	4.3496 mm
8	0.00000001	1.1132 mm	1.0247 mm	.7871 mm	.43496 mm

Encoding geo info in the name

- Advantages:
- Prefix matching can be done at the NDN layer without knowing the name semantics
- Reversible encoding => potentially less metadata required
- No performance impact
- Enables Geographic routing through the NDN Strategy Layer

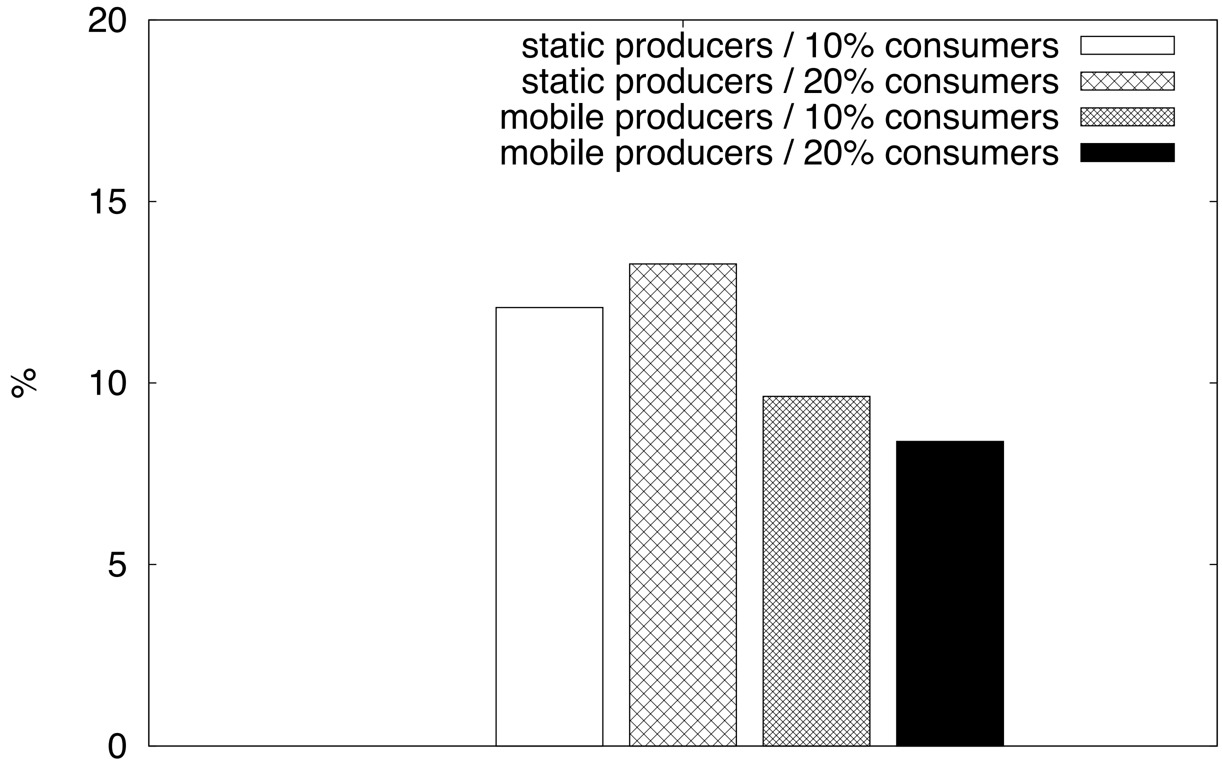
- Limitations:
- Only rectangular areas

Preliminary Results

- **Application: Park Finder (using NDNSIM/NS3)**
  - Cars issue an interest searching for a parking structure with spots in a certain area.
  - NDN nodes with the information can respond.
- **Simulations in the Santa Monica Area**
  - The mobility trace contains a total of 695 cars traveling in a 2100m x 2100m residential neighborhood of Santa Monica, CA, for 5 minutes.
- **Simulation Scenarios:**
  - We devised 4 different simulation scenarios:
    - 20 static producers, 70 consumers
    - 20 static producers, 140 consumers
    - 140 mobile producers, 70 consumers
    - 140 mobile producers, 140 consumers

Preliminary Results

- **Metrics:**
  - Percentage of extra interests satisfied by the Content Store thanks to our naming scheme.
  - Time required to satisfy an interest.



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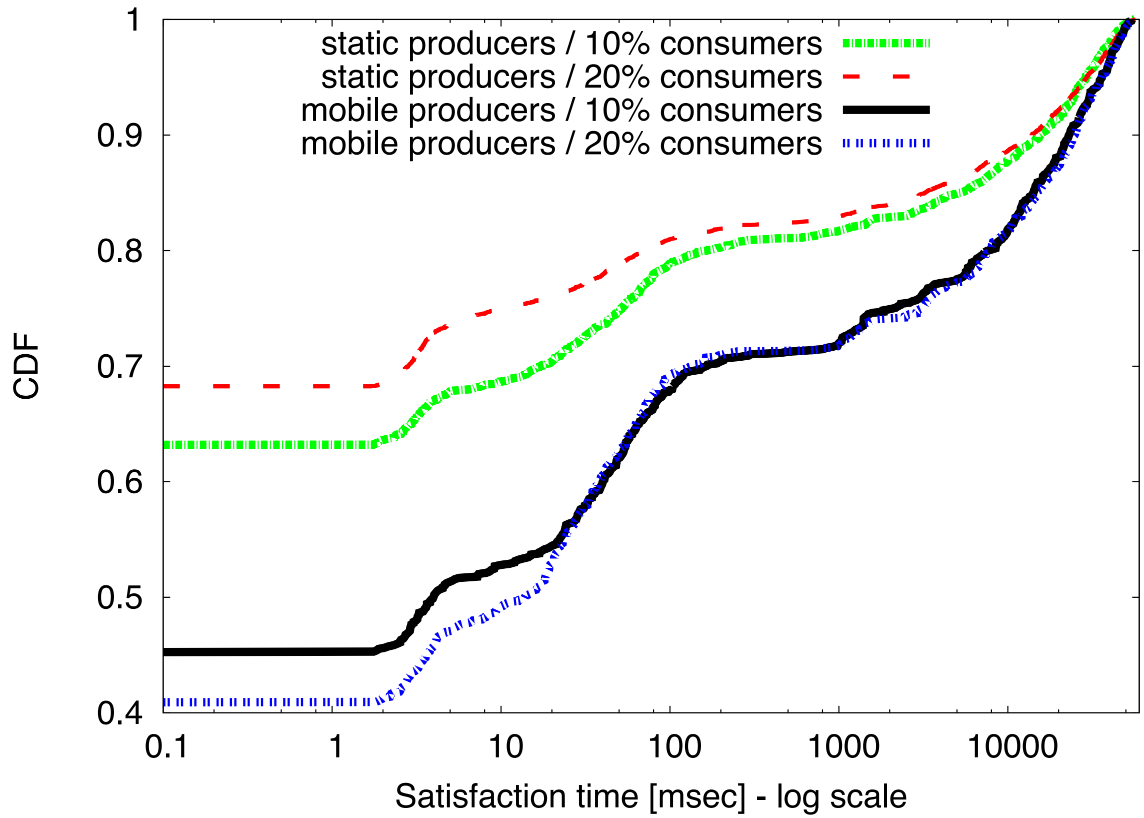

Forwarding in V2V

- Potentially, if a car blindly forward an interest, this could be spread all over the city, causing useless transmission and, most important, increasing the probability of collision among packets.
- But:
- When an interest is about a specific area, do we really need to forward it in all the available directions?
- Do we really need to hear a retransmission (implicit ack) from all the directions to consider a packet as acked?
- Could limit the forwarding to a specific area be a good approach to limit the number of useless transmission without affecting the probability to get the desired content?

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The need of a field trial

- Investigate the overall feasibility and performance on NDN in Urban Scenarios.
- Study the noise generated by third-party transmitters (i.e. APs in homes, buildings or on the road) may affect NDN packet delivery
- Investigate on the Role of Cache in actual low-density scenarios factoring-in the impact of vehicle concentration/dispersion due to traffic regulators (e.g. Traffic Lights/Stop signs etc.)
- Have a preliminary performance evaluation on the field to guide future developments

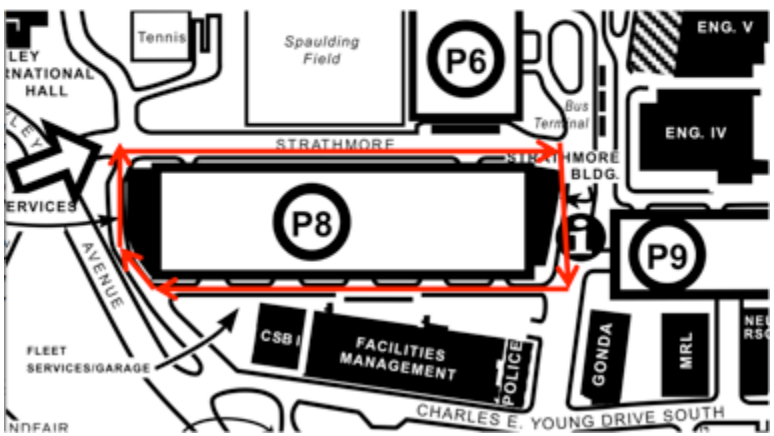
Two Simple Application Scenarios

- **<u>Info-Traffic Application:</u>**
  - **Consumer** asks for traffic information for a specific area
  - **Producer** responds to the interest with the proper content. The producer can be any car that has been in the area or has the requested information in the cache.
  - Note that in this case the <u>content</u> is a single data packet.

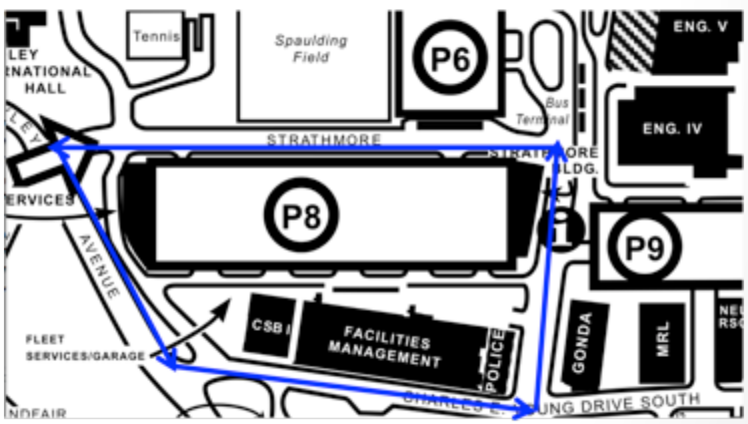
- **<u>Traffic Photo Application:</u>**
  - **Consumer** requests a picture in a specific area (e.g. a specific intersection)
  - **Producer** (a car in that area) upon receiving the interest
    - Takes a picture using the on-board camera
    - Sends the picture back to the consumer
    - <u>Note</u> the content (Picture) usually takes several packets which need to be sent across the network.

Multicar Experiment Mobility Patterns

- **4 vehicle running clockwise around P8 as shown in (a)**
- **6 vehicles running counterclockwise to cover a larger road block as shown in (b)**
- **Car speeds ranged from 6.3m/s to 21.2m/s (14-47mph)**
- **Allowing vehicles traveling in opposite directions to meet briefly for packet exchange**

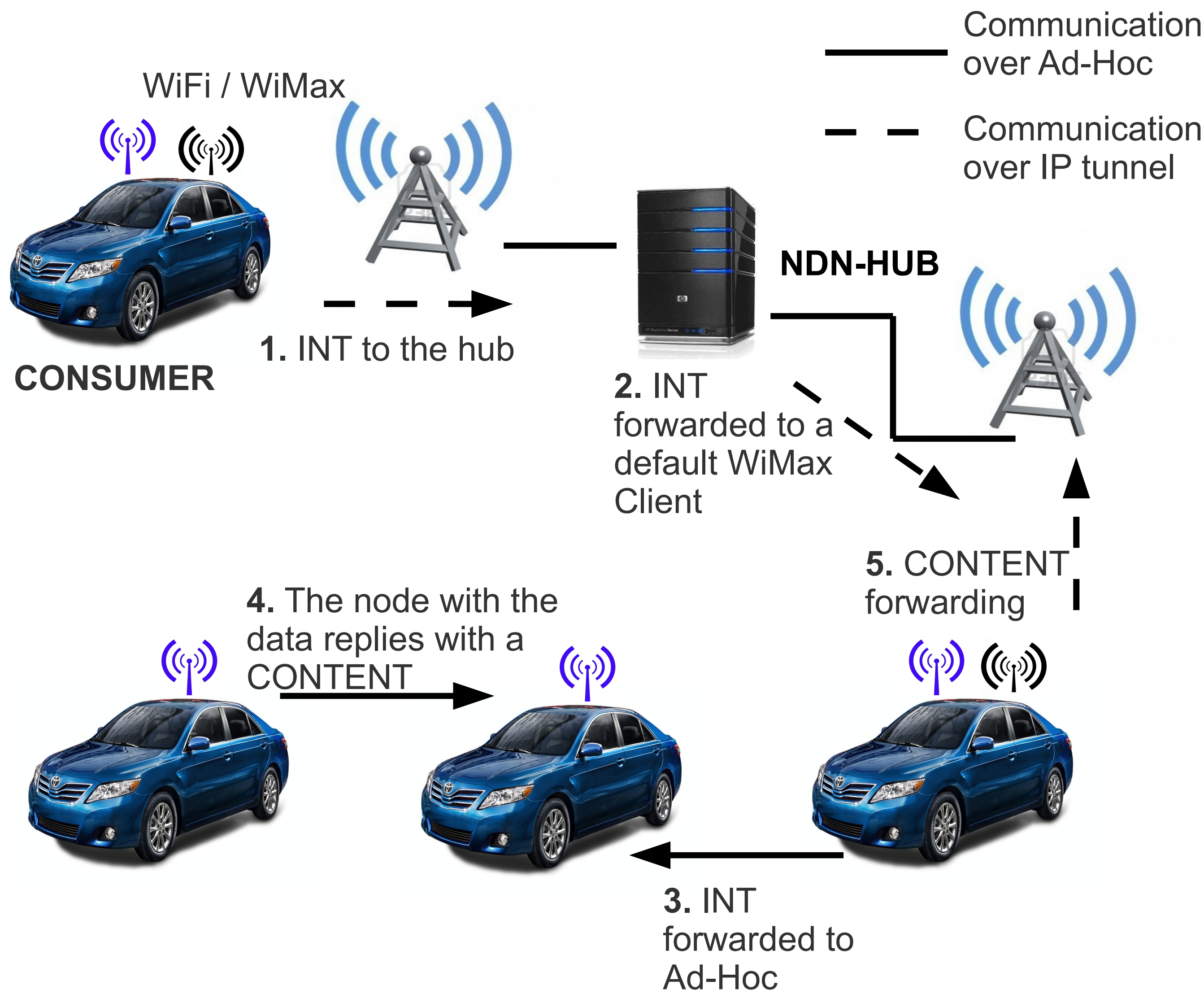


(a) V-NDN Driving Route, Clock Wise one block around Parking Lot 8



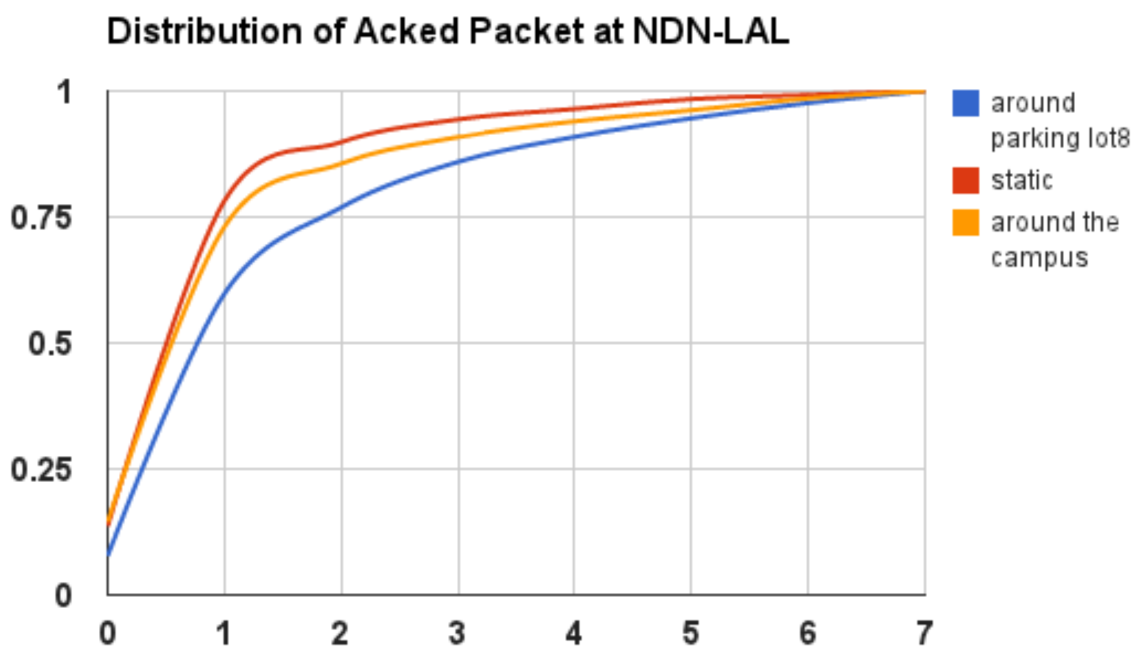
(b) Counter-Clock Wise two blocks around Parking Lot 8

Experimental Scenario(s)



WiFi Broadcast

- **Link Adaptation Layer (LAL) transmission**
  - static case: ~75% of all packets need 1 LAL retransmission*
  - mobility case: ~65% of all packets need 1 retransmission.
  - ~95% packets received ACK within 5 retransmissions.



* It was discovered afterwards that the WiFi cards on 3 vehicles was disfunctioning during the static testing, hence the poorer performance than the mobile case. This problem also affected the performance shown on the next slide.


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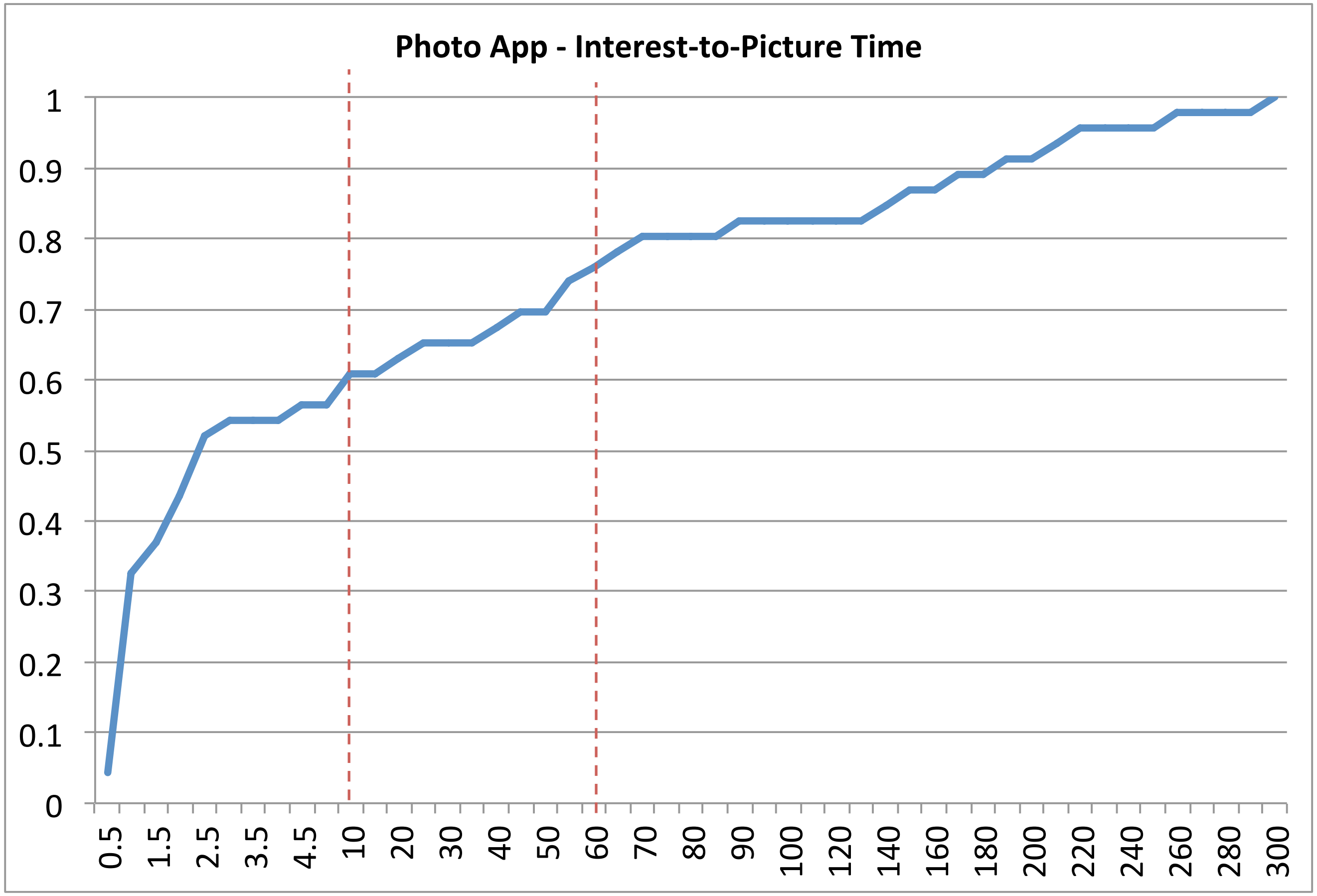
Photo Application Measurements

- **Another application was a photo-request/response for a specific location.**
- **This application emulates the request of a visual information from a particularly congested area.**
- **The Consumer issued an interest for a photo and the producer replied with a picture taken in real time by the camera on board of the vehicle.**

Photo Application: Results



- **60% was received in less than 10 Seconds**
- **76% was received in less than 1 minute**
- **95% was received in 3 minutes 20seconds**

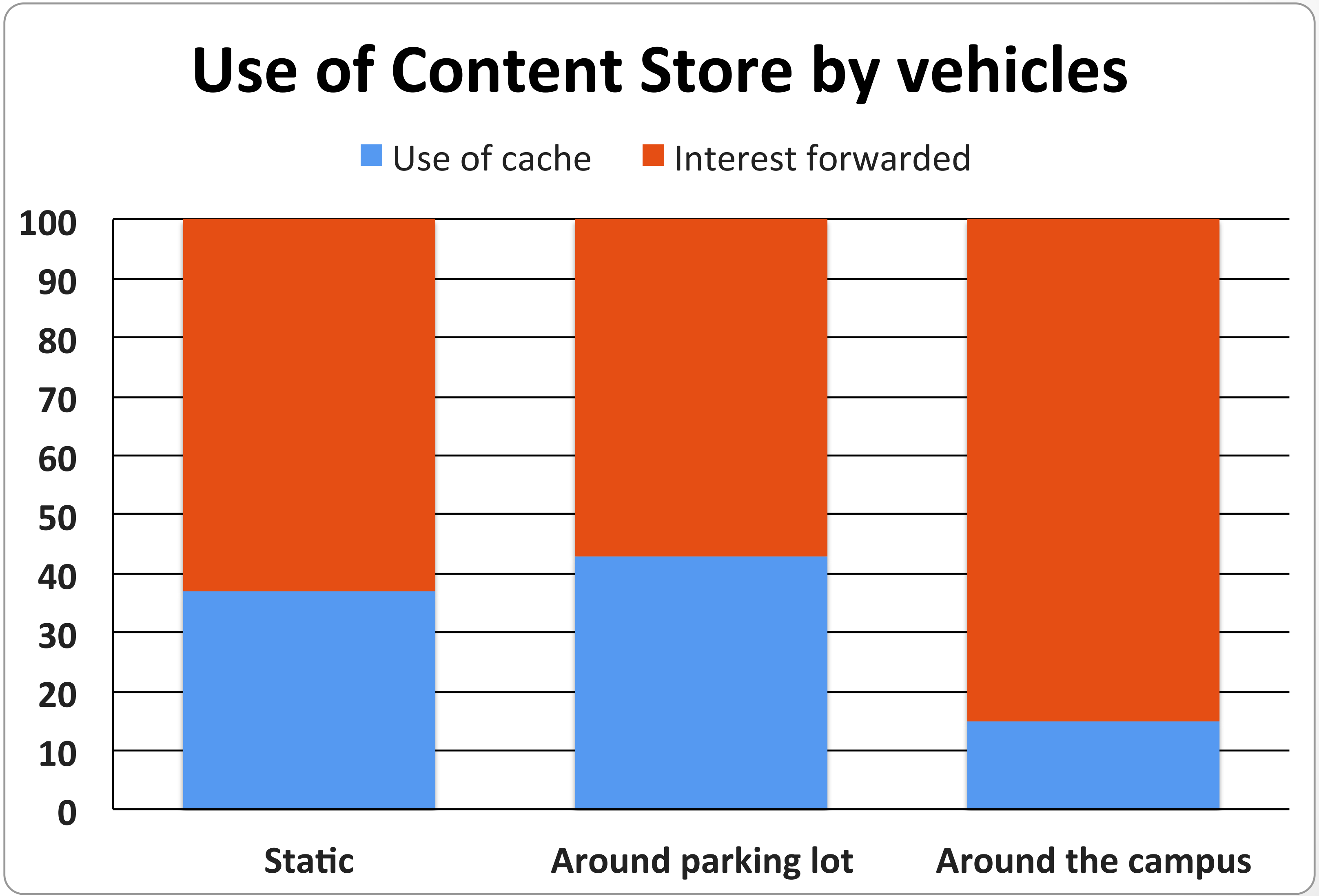
Photo Application Results

- **Total of 51 pictures**
  - The average number of data packets per picture: 4.8 packets
    - Packet size: 1200 bytes
    - The largest picture took 9 packets for delivery.
  - Interest-to-Picture time:
    - Min=0.011 seconds, Max=298.3 seconds
    - Median= 2.35 seconds, Average=46.8 seconds

- **Lesson Learned:**
  - It is possible to transmit media-rich information even with a low density network based on just 10 cars
  - NDN Cache helps to cope with such low density.

Caching in Action

- **Content Store Usage**



Multi-homing

- **Two nodes were equipped with Both WiMax and VANET interfaces therefore data set is limited.**
- **Dataset is limited due to the coverage area however initial test confirms NDN is able to seamlessly handle multi-homing. About 450 interests where satisfied through WiMax at some point in the path.**

Cache Role

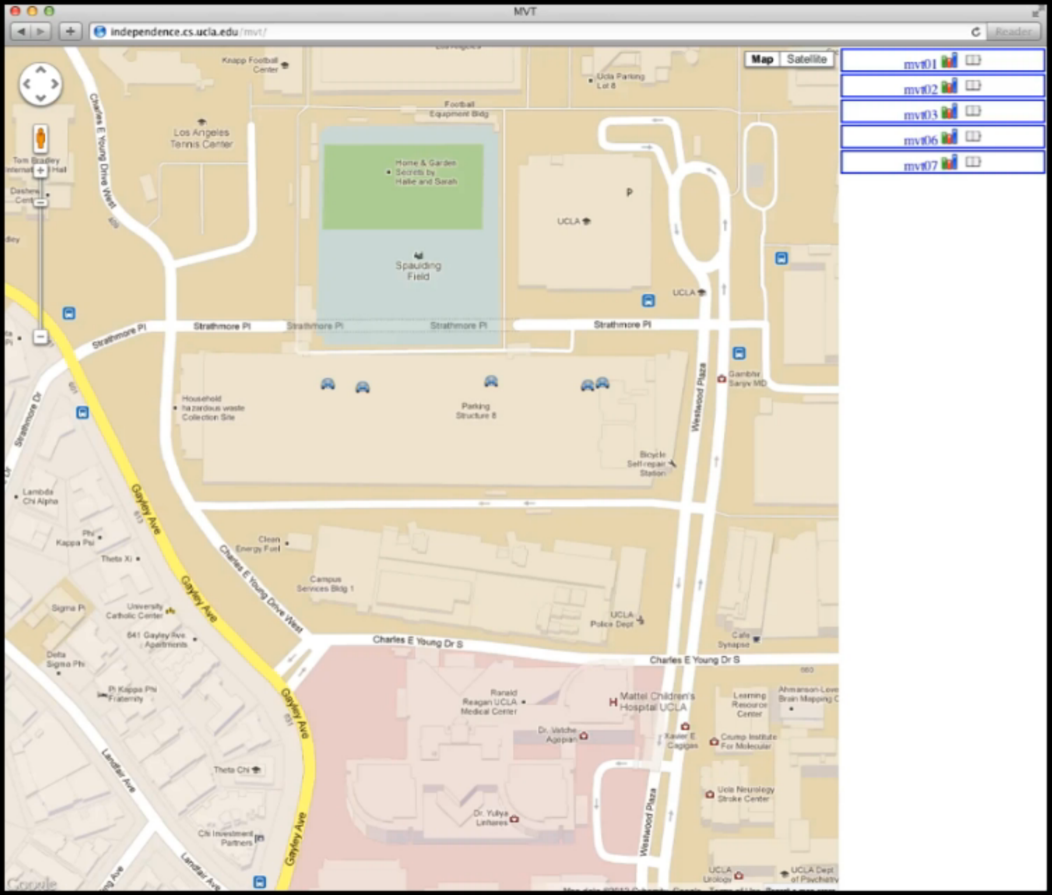
- **Experiments were performed around UCLA Campus with 10 vehicles running around two blocks.**
- **Interest Forwarding Analysis (STATIC CASE)**
  - Interest Forwarded: 29,686
  - Interest Satisfied by Cache: 11,218
- **Interest Forwarding Analysis (MOBILE CASE)**
  - Interest Forwarded: 24,852
  - Interest Satisfied by Cache: 8,404
- **Lesson:**
  - Cache accounts for a substantial portion of V-NDN data delivery.

A short video recording of the 10-car demonstration:
https://docs.google.com/file/d/0BzW2B79XAxm2aTh6UGtScDVwYTQ/edit?usp=sharing

VNDN Code 0.1

- **Where:**
  - http://tinyurl.com/k4p3fs9
  - https://github.com/named-data/vndn
- **Contacts:**
  - Davide Pesavento davidepesa@gmail.com
  - Giulio Grassi giulio.grassi86@gmail.com
  - Giovanni Pau gpau@cs.ucla.edu
- **VNDN will be integrated in the NDN project main code branch.**

An Experiment Snapshot



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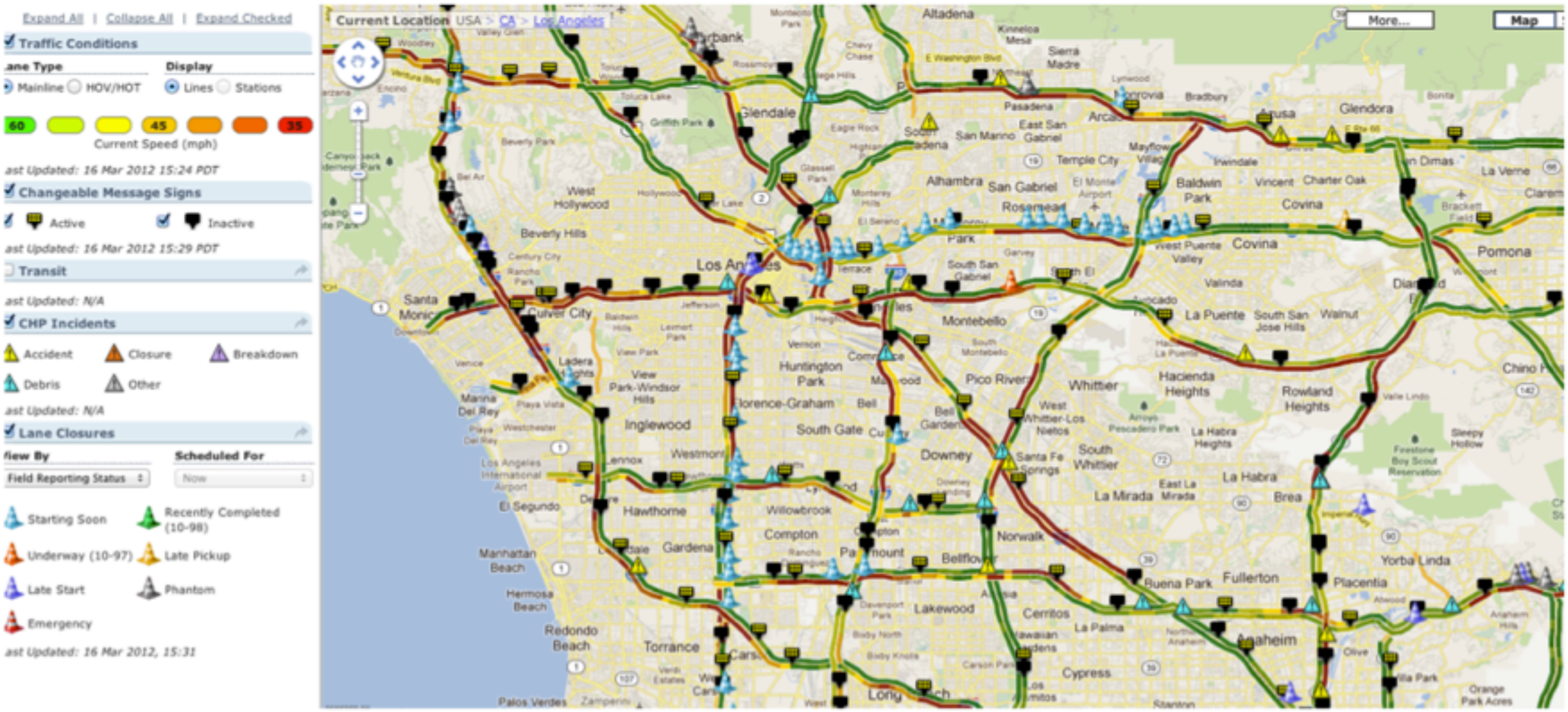
That’s all

Thank you for your attention.

Questions?

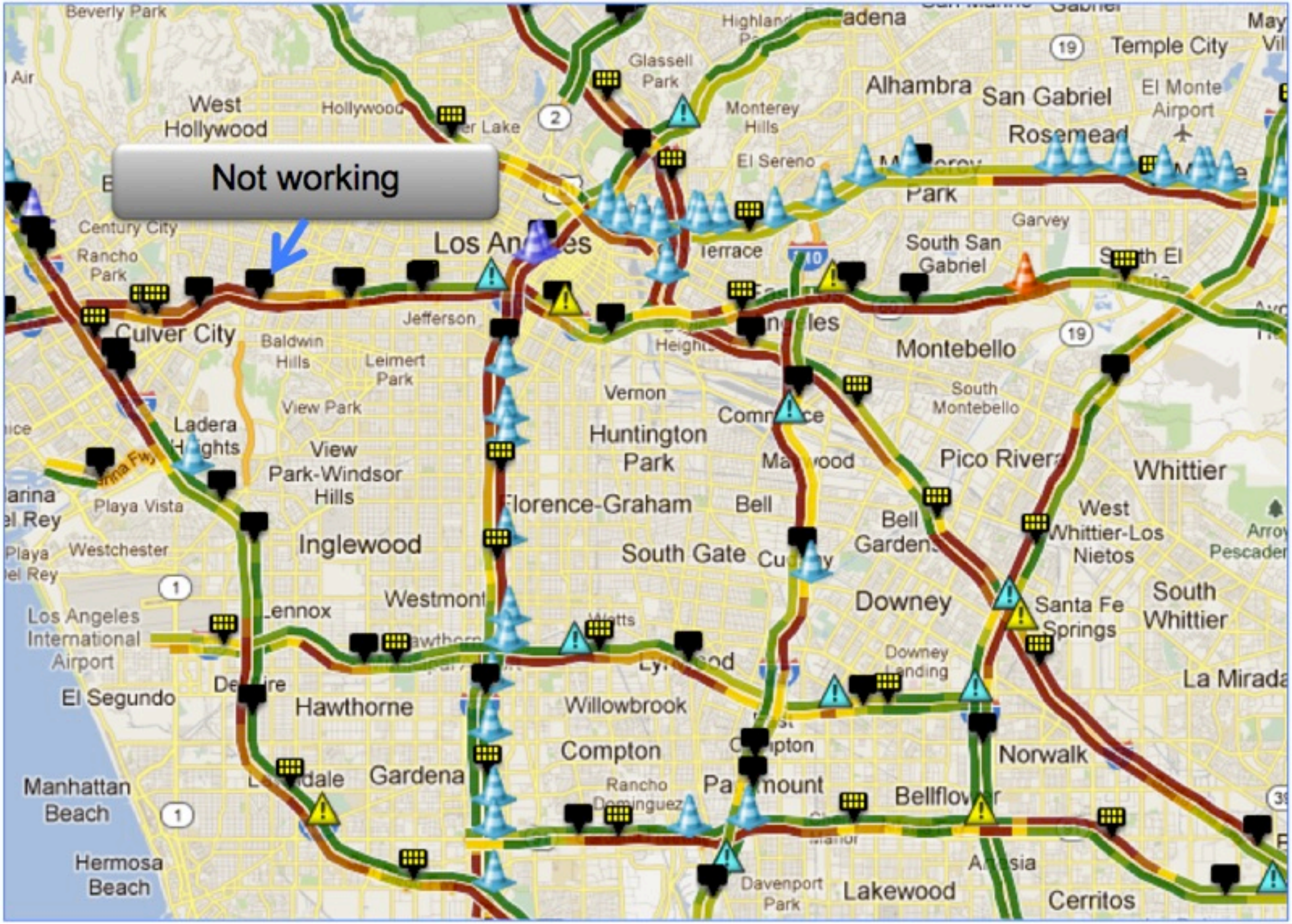
gpau@cs.ucla.edu

Traffic Services Today

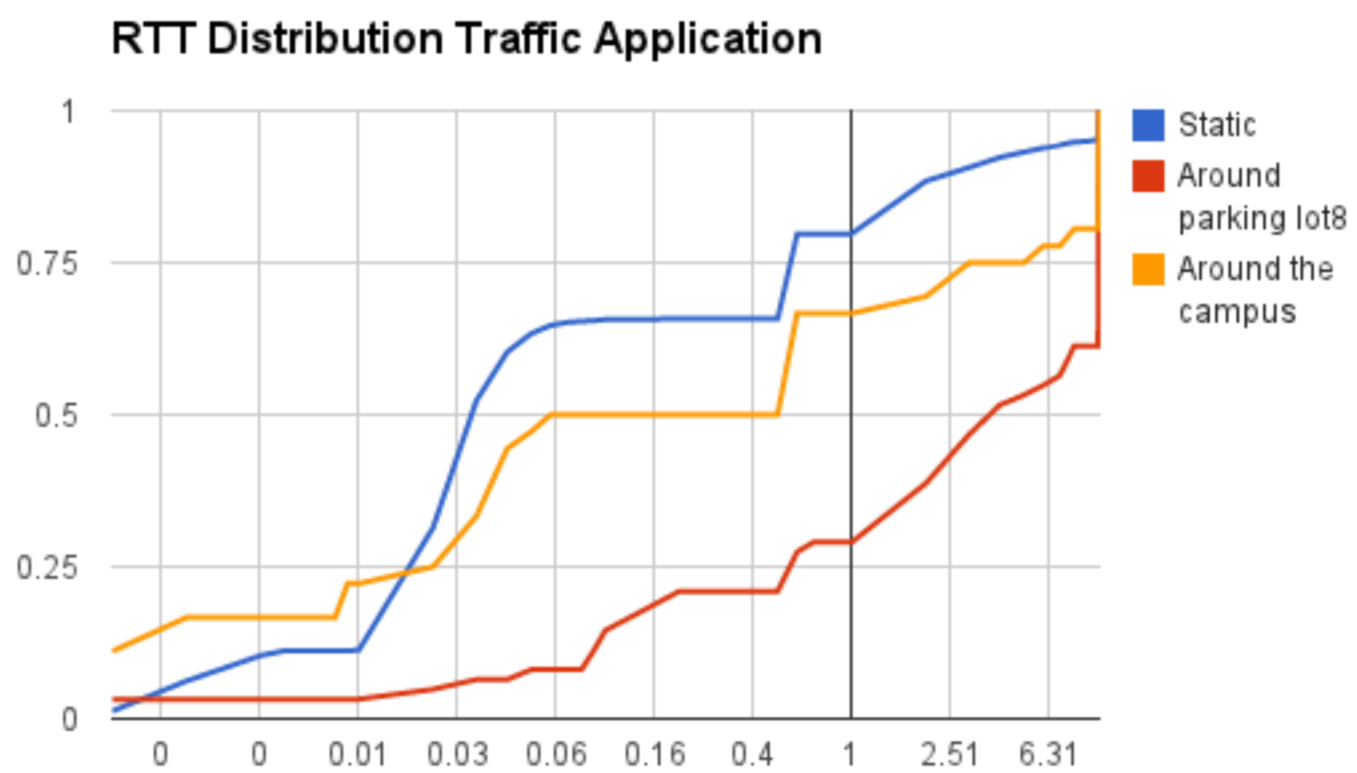


Source California, Dept. of Transportation

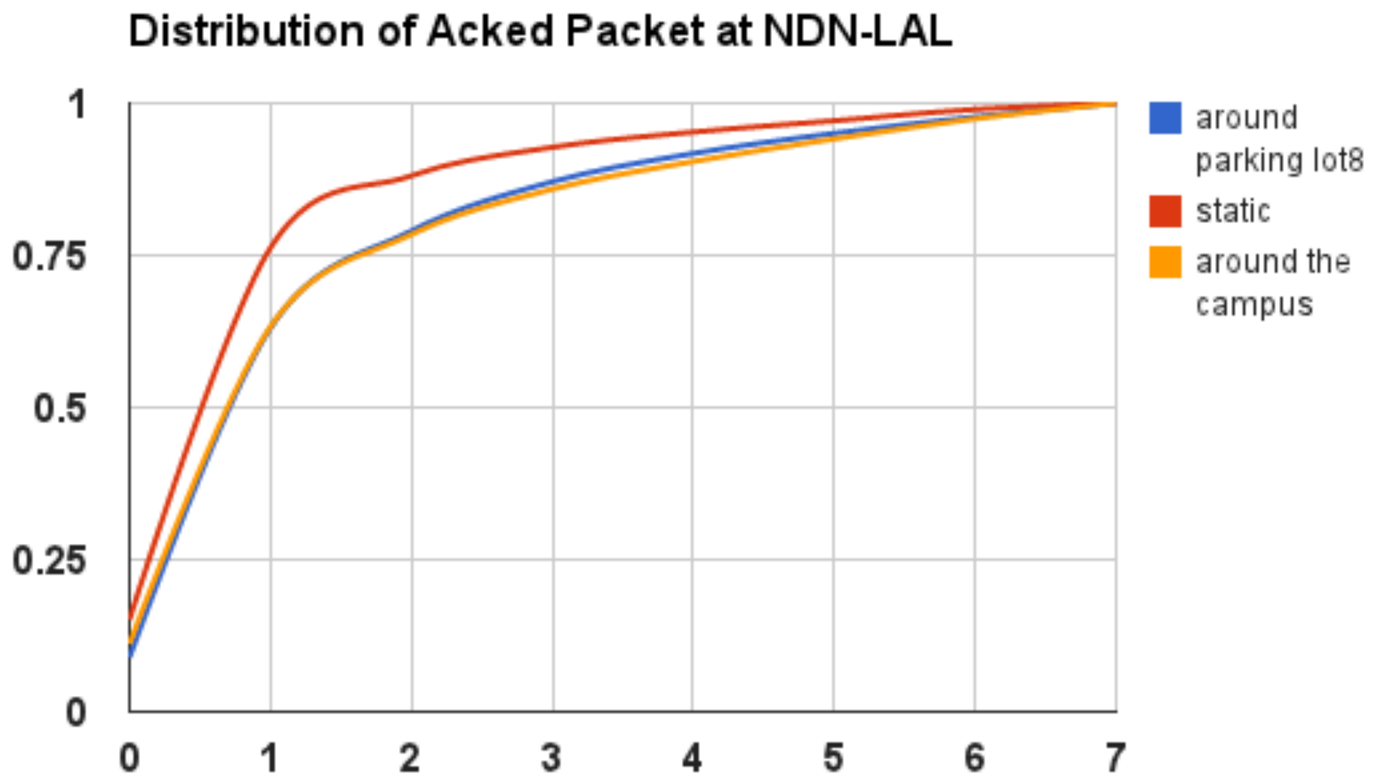
Traffic Services Today



Preliminary Results

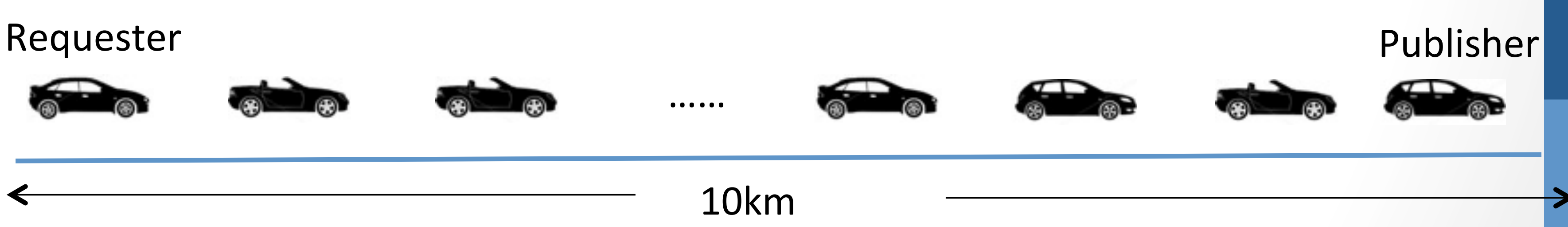


Preliminary Results

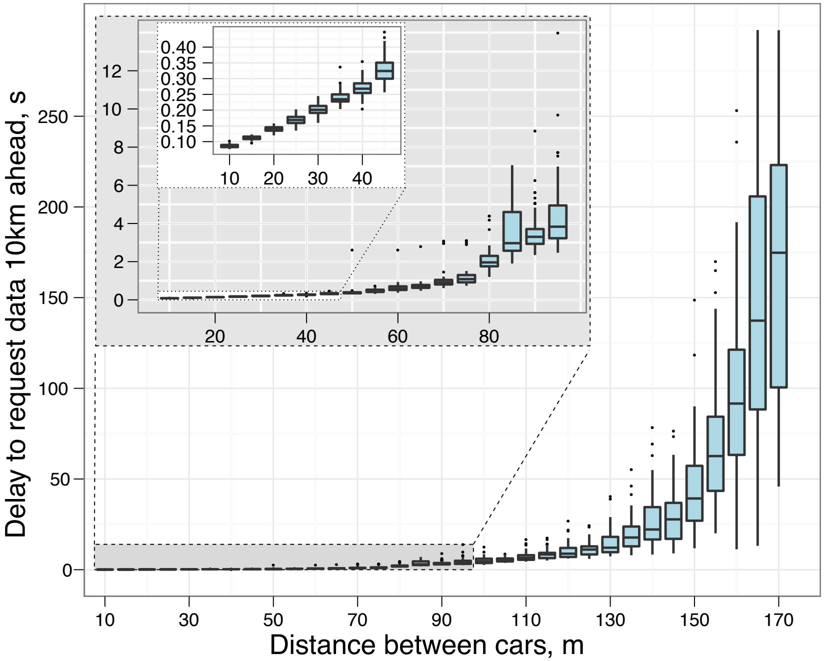


Initial investigation into feasibility

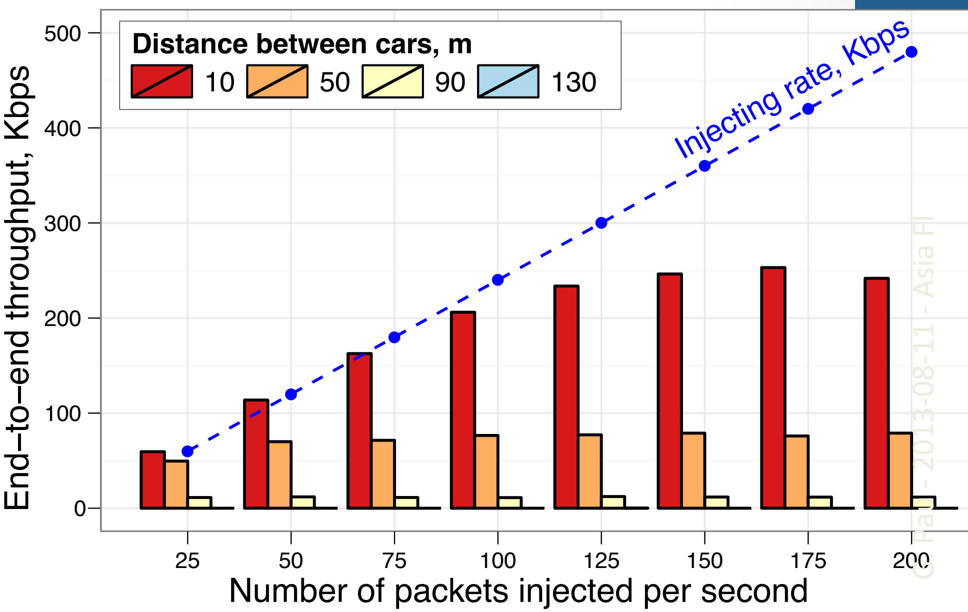
- **Simulation setup**
  - Mac layer: Ad-hoc WiFi (802.11a)
  - Physical layer:
    - transmission power 5dbm
    - Nakagami propagation process
    - Energy detection threshold -96.0 dbm
  - Mobility model
    - Straight highway with length 10km
    - Cars move at constant speed of 60mph



Simulation Results



Data retrieval delay



Long distance end-to-end throughput

Vehicles @ Macau

The Fun Stuff

Mesh Node

WiMax Station

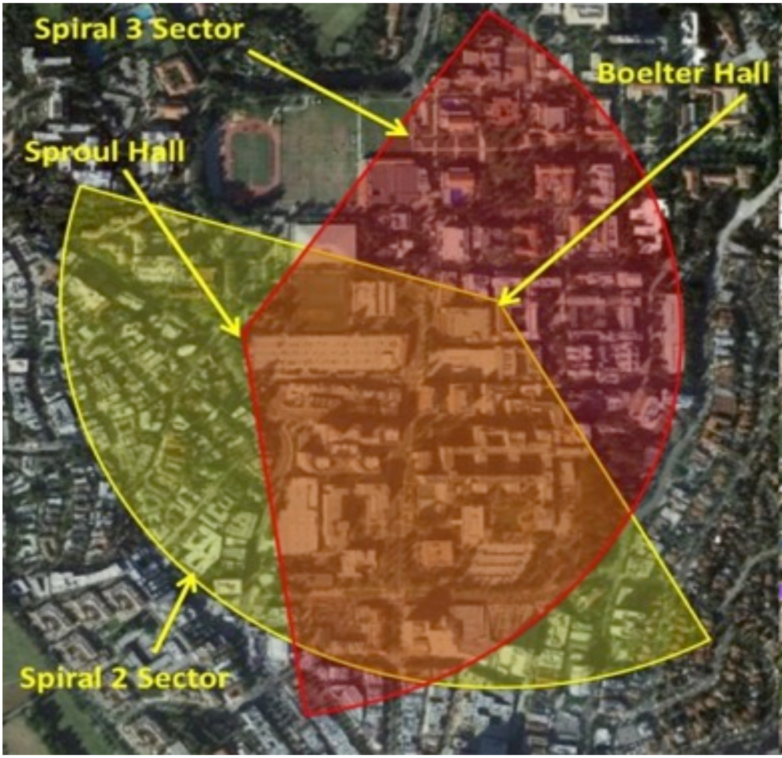
El Mirage Dry Lake Setup

Mobile Node

Car Node

Sensor Platform

WiMax and V2I Coverage



Backup Material

L2 Implicit Ack

NDN V2V Link Adaptation Layer

- **Mobility changes the underneath topology**
  - ALL transmissions are made in broadcast
    - **Current** WiFi protocol is designed for point-to-point, **no L2 feedback for broadcast**.

  - To limit flooding, Only the **<u>furthest</u>** away node from the last sender forwards the packet.
    - The mechanism uses distance info from GPS coordinates plus small randomized waiting.
  - Hearing a packet's further forwarding is used as implicit-ack
    - If the implicit ack is not over-eared by the transmitter, the packet is quickly retransmitted (up to 7 times).
    - Using simulation to understand the trade-offs on the number of retransmissions and timing.

NDN V2V Link Adaptation Layer

- **Additional Issues:**
  - In urban scenarios defining the **furthest** is tricky: at intersections is essential to explore all the directions (especially in Interest forwarding).
  - We are studying two approaches via simulation:
    - Using the angle between implicit-ack transmitter and the current node to estimate if implicit-acks are covering all the directions (**NO MAP**)
    - Using a Location Service able to perform reverse geocoding and determine which directions the implicit-ack covered (**USE OF DIGITAL MAPS**).
  - When we consider a packet ihas made progress in urban scenarios?
    - Current approach is to have a "TOS" field that can be used to determine the progress.

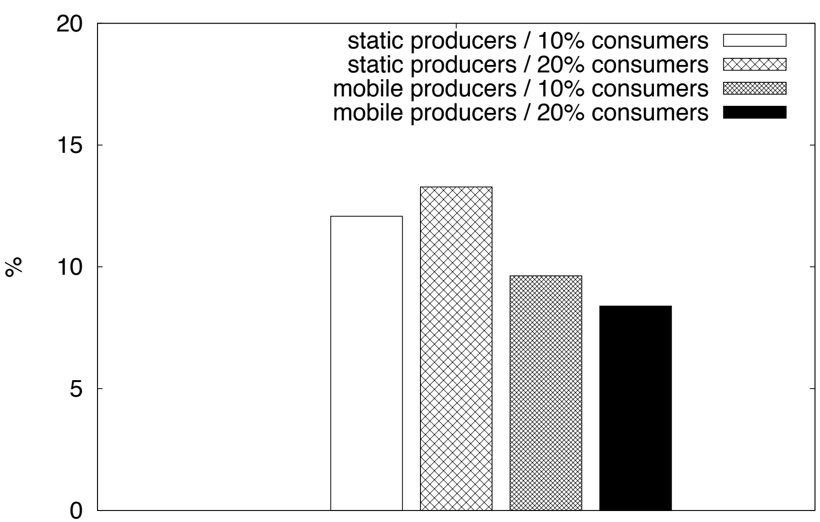
Naming Results

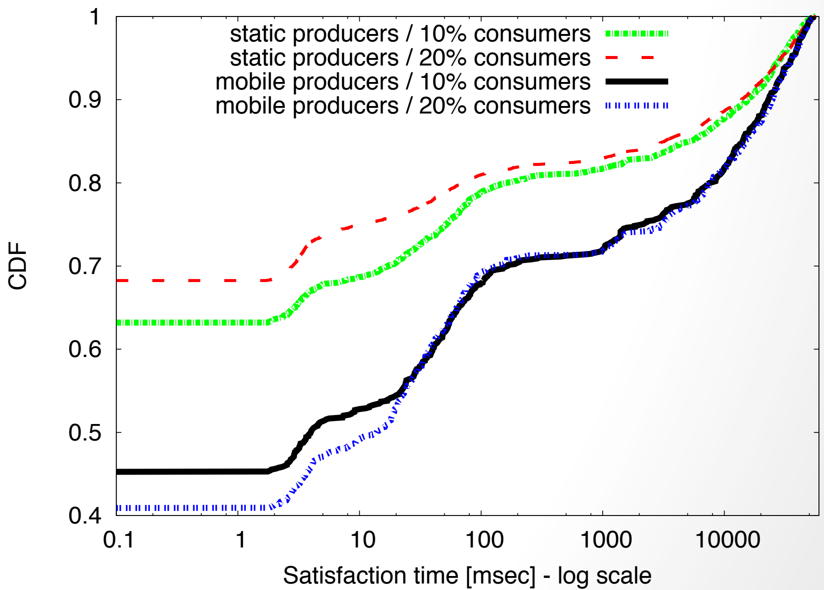
Preliminary Results

- **Application: Park Finder**
  - Cars issue an interest searching for a parking structure with spots in a certain area.
  - NDN nodes with the information can respond.
- **Simulations in the Santa Monica Area**
  - The mobility trace contains a total of 695 cars traveling in a 2100m x 2100m residential neighborhood of Santa Monica, CA, for 5 minutes.
- **Simulation Scenarios:**
  - We devised 4 different simulation scenarios:
    - 20 static producers, 70 consumers
    - 20 static producers, 140 consumers
    - 140 mobile producers, 70 consumers
    - 140 mobile producers, 140 consumers

Preliminary Results

- **Metrics:**
  - Percentage of extra interests satisfied by the Content Store thanks to our naming scheme.
  - Time required to satisfy an interest.





- **Scenario: static producer; 69 consumers:**
  - interest issued: **5481**, interest satisfied **3294**(60%), interest satisfied by producer 487, int satisfied by CS 2795, interests satisfied by CS due to to cantor approach 398
- **Scenario: static producer; 140 consumers:**
  - interest issued: 11173, interests satisfied **6688**(60%), interests satisfied by producer 595, int satisfied by CS **6074**, interests satisfied by CS due to cantor **888**

Forwarding in V2V

- Potentially, if a car blindly forward an interest, this could be spread all over the city, causing useless transmission and, most important, increasing the probability of collision among packets.
- But:
- When an interest is about a specific area, do we really need to forward it in all the available directions?
- Do we really need to hear a retransmission (implicit ack) from all the directions to consider a packet as acked?
- Could limit the forwarding to a specific area be a good approach to limit the number of useless transmission without affecting the probability to get the desired content?

Notes:

- **Integration with Wired implementations**
  - Some policies differ, the GW shall carefully handle potential conflicts.
    - i.e. In V2V we retransmit on the same interface, in an hybrid environment the gateway shall prevent the packet from going back to the same wired interface
- **Is there a case for long-lived interests in v2v ?**
  - Warnings
  - Traffic conditions
  - …

- **Scenario: mobile producer; 69 consumesr: interest issued: 5368, interest satisfied 1121, interest satisfied by producer 421, int satisfied by CS 699, int satisfied by CS graze a cantor 108**
- **scenario con producer mobile, 140 consumer: interest issued: 4382, interest satisfied 894, interest satisfied by producer 312, int satisfied by CS 582, int satisfied by CS graze a cantor 75**

That's all

Thank you for your attention.

Questions?

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