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When will vehicular computing become pervasive?

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Why do we need vehicular networks?

- PAYMENTS - Toll Collection
- PAYMENTS - ITS Service Payment
- PAYMENTS - Other ePayments
- PAYMENTS - Rental Car Processing
- PAYMENTS - Parking Payment
- PAYMENTS - Food Payment
- PAYMENTS - Fuel Payment
- SAFETY - Vehicle-to-vehicle Data Transfer
- SAFETY – Highway-Rail Intersection Warning
- Traffic Information - Audio Transfer - Streaming
- Traffic Information - Map Updates
- Traffic Information - Mobile Internet
- Traffic Information - Traffic Data
- Traffic Information - Traveller Information
- Traffic Information - Vehicle Registration (EVI)
- Traffic Information - Transit Vehicle Priority
- Traffic Information - Diagnostic Data Transfer
- Traffic Information - Video Transfer - Block
- Traffic Information - Audio Transfer - Block
- Traffic Information - Video Transfer - Streaming
- Traffic Information - Repair Service Record
- Traffic Information - Vehicle Software Updates
- VSC - OBU-to-OBU - Approaching Emergency Vehicle
- Warning
- VSC - OBU-to-RSU - Emergency Vehicle Signal Preemption
- VSC - OBU-to-RSU - Intersection Emergency Vehicle
- Approaching
- VSC - RSU to OBU - Emergency Scene Data
- Networking
- VSC - OBU-to-OBU - Emergency Scene Data
- Networking
- VSC - OBU-to-OBU - Cooperative Collision Warning
- VSC - RSU to OBU - Map Downloads and Updates
- VSC - RSU to OBU - Enhanced Route Guidance and
- Navigation
- VSC - RSU to OBU - GPS Corrections
- VSC - RSU to OBU - Adaptive Headlight Aiming
- VSC - RSU to OBU - Adaptive Drivetrain Management
- VSC - RSU to OBU - Merge Assistant
- VSC - RSU to OBU - Sign Information (warning
- assistance)

Why do we need vehicular networks? (contd')

- VSC - RSU to OBU - Point-of-Interest Notification
- VSC - RSU to OBU - Curve Speed Warning
- VSC - RSU to OBU - Highway/Rail Collision Warning
- VSC - RSU to OBU - Animal Crossing Zone Information
- VSC - RSU to OBU - Low Bridge Warning
- VSC - RSU to OBU - Work Zone Warning
- VSC - RSU to OBU - Stop Sign Warning
- VSC - RSU to OBU - Keep Clear' Warning
- VSC - RSU to OBU - Wrong-way Driver Warning
- VSC - RSU to OBU - Left Turn Assistant
- VSC - RSU to OBU - Infrastructure Intersection Collision
- Warning
- VSC - RSU to OBU - Pedestrian Crossing Information
- VSC - RSU to OBU - Pedestrian/Children Warning
- VSC - RSU to OBU - School Zone Warning
- VSC - RSU to OBU - Stop Sign Movement Assistance
- VSC - RSU to OBU - Traffic Signal Warning
- VSC - RSU to OBU - Low Parking Structure Warning
- VSC - OBU-to-RSU - SOS Services
- VSC - OBU-to-RSU - Post-Crash Warning
- VSC - OBU-to-RSU - Just-in-Time Repair Notification
- VSC - OBU-to-RSU - Intelligent On-ramp Metering
- VSC - OBU-to-RSU - Intelligent Traffic Lights
- VSC - OBU-to-RSU - Blind Merge Warning
- VSC - OBU-to-RSU - Infrastructure-based Traffic Probes
- VSC - OBU-to-OBU - Pre-crash Sensing
- VSC - OBU-to-OBU - Intersection Collision Warning
- VSC - OBU-to-OBU - Enhanced Differential GPS Corrections
- VSC - OBU-to-OBU - Highway/Rail Collision Warning
- VSC - OBU-to-OBU - Vehicle-based Road Condition Warning
- VSC - OBU-to-OBU - Road Feature Notification
- VSC - OBU-to-OBU - Curve Speed Warning
- VSC - OBU-to-OBU - Visibility Enhancer
- VSC - OBU-to-OBU - Electronic Brake Lights
- VSC - OBU-to-OBU - Hybrid Intersection Collision Warning
- VSC - OBU-to-OBU - Instant (Problem) Messaging
- VSC - OBU-to-OBU - Blind Merge Warning
- VSC - OBU-to-OBU - Post-Crash Warning
- VSC - OBU-to-OBU - Merge Assistant
- VSC - OBU-to-OBU - Lane Change Assistant
- VSC - OBU-to-OBU - Left Turn Assistant
- VSC - OBU-to-OBU - Stop Sign Movement Assistant
- VSC - OBU-to-OBU - Cooperative Glare Reduction
- VSC - OBU-to-OBU - Blind Spot Warning
- VSC - OBU-to-OBU - Platooning
- VSC - OBU-to-OBU - Cooperative Adaptive Cruise Control

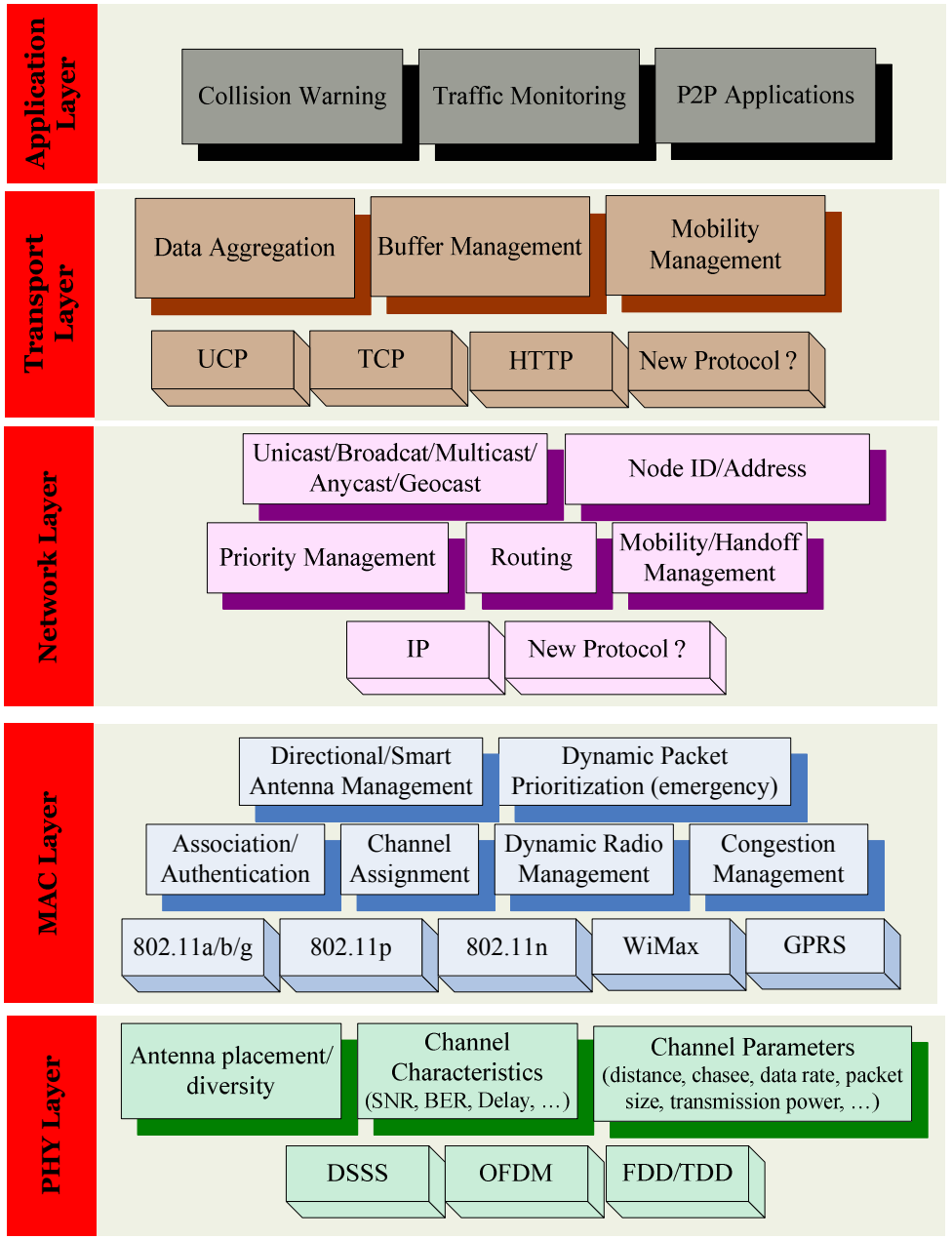
So ….

Emerging vehicular applications pose a host of completely new requirements and challenges

System Requirements and Challenges?

- Network Management
  - Physical Layer: Antenna placement/diversity, Directional/smart antenna, SNR, BER, transmission power, …
  - MAC Layer: Association/Authentication, Channel Assignment, Channel Prioritization, Dynamic Radio Management, Congestion Management, Directional/Smart Antenna Management, Dynamic Packet Prioritization (emergency), …
  - Network Layer: Unicast/Broadcast/Multicast/Anycast/Geocast, Node ID/Address, Routing, Mobility/Handoff Management, Security, Privacy, ...
- Data Management
  - Large amount of data / Storage
  - Filtering and Caching
  - Integrity and Consistency
  - Continuous multimedia streams
  - Real-time processing/querying
  - Centralized vs. Distributed

Vehicular Communication Stack

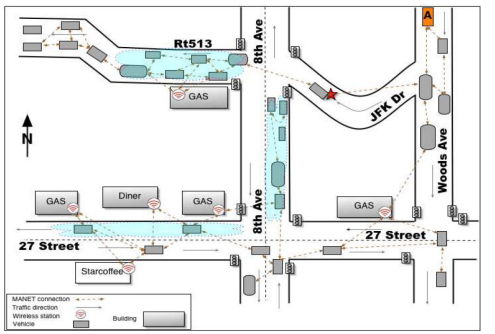


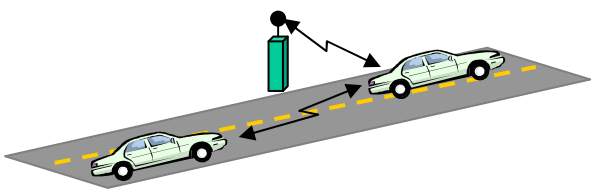
Main Challenge ….

Testing environments for Car-to-Car and Car-to-Road are critical for the identification and investigation of the network performance and system requirements needed to support these new applications

Testing Environments

- Experimental Testbeds
  - Campus/city-wide testbed (10s~100s vehicles, or more?)
  - Vehicles:
    - private cars (compact, large, SUV, …)
    - Shuttles or buses
    - Trucks and trailers
  - Equipments:
    - Radios: WiFI, 802.11p, 3G, Bluetooth, MIMO, …
    - Sensors: GPS, cameras, radars, ladars, acoustics sensors, on board sensors, …
    - On-Board units (antenna position, antenna diversity, …) & Road-Side units (Rooftop, traffic lights, road signs, cat-eyes, ….)
  - Radio channel emulator that can reproduce the vehicle radio channel under various conditions
  - Traffic Generator for realistic mobility pattern and realistic driver behavior (traffic data bases)



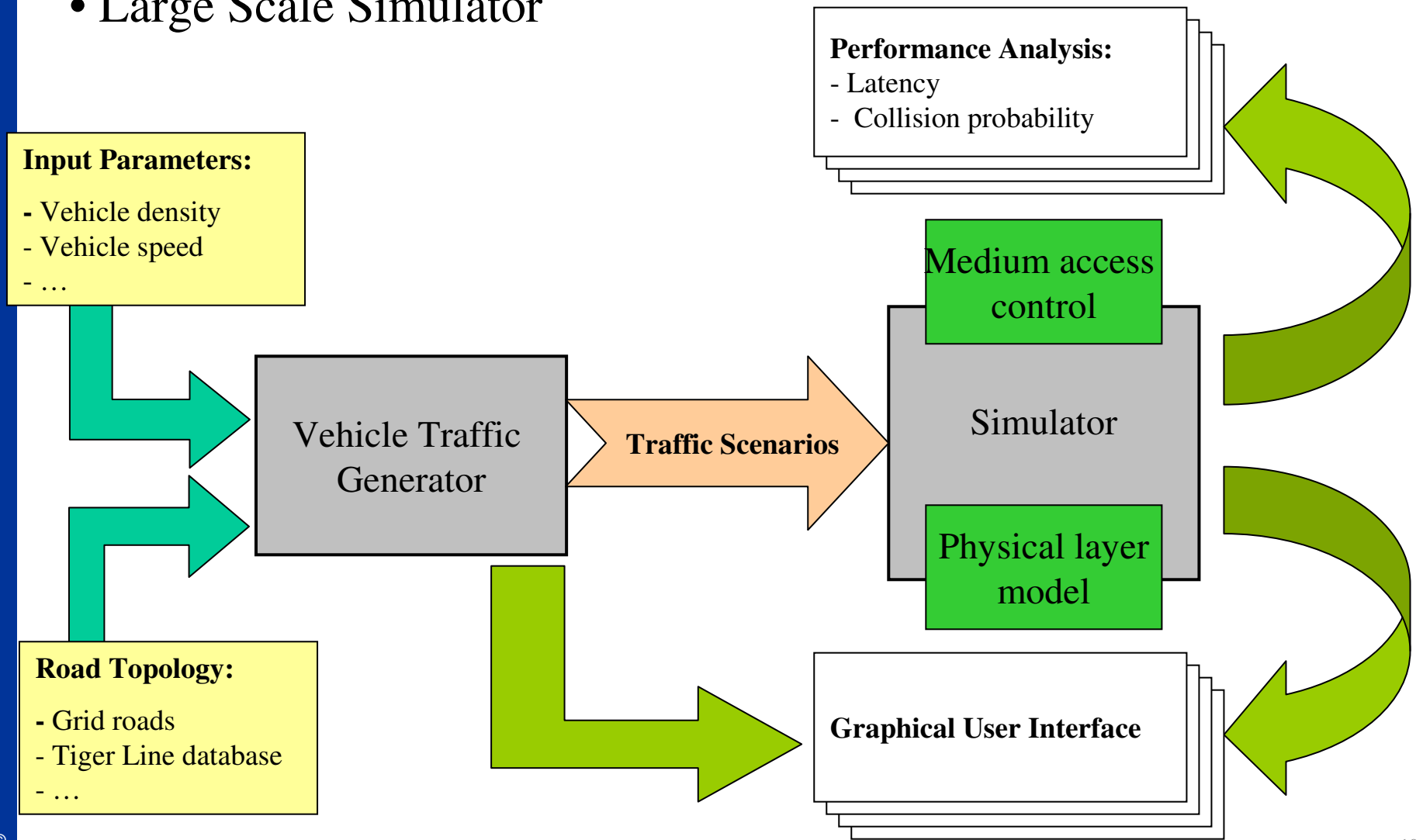


But …

- Hard to repeat an experiment
- Dangerous to experiment in real situation
- Unfeasible of running large scale experiment

Testing Environments II

- Large Scale Simulator



Testing Environments III

- Hybrid emulation capability!
  - Interconnects the real car testbed with a simulated environment

Other Challenges?

Driver/Passenger-Car Interface !

Incremental Deployment !

Regulations !

Collaborations !

Initiatives

- VII Program
  - Aimed at a proof of concept demonstration
  - Goal is to test ability of system to deliver public and private services
  - Identify technical issues that require additional work
  - Provide testbed for applications and services
  - Implemented through contracts and cooperative cost share agreements with FHWA
  - Proof of Concept testing
    - Component testing spring 2007
    - Road testing summer/fall 2007
- IEEE 1609
  - P1609.1, Resource Manager
  - P1609.2, Application Services
  - P1609.3, IP Network Services
  - P1609.4, Medium Access Control (MAC) Extension Services
- 802.11p
  - Define enhancements to 802.11 required to support Intelligent Transportation Systems (ITS) applications.
  - Includes data exchange between high-speed vehicles and between these vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz
  - Expected publication date April 2009.

Vehicular Applications vs. Deployment