Trustworthy Foundation for CAVs in an Uncertain World: From Wireless Networking, Sensing, and Control to Software-Defined Innovation Platforms

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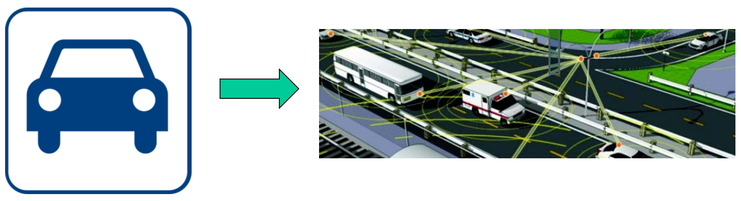
CAV: Opportunities and Challenges

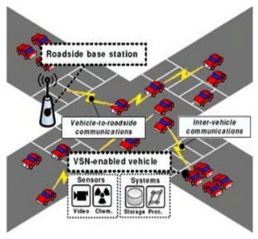
Vehicle paradigm shift



Individual, human-driven vehicles

Connected, automated vehicles (CAV)

Driving safety



Eliminate up up to 90% accidents

Networked fuel economy optimization

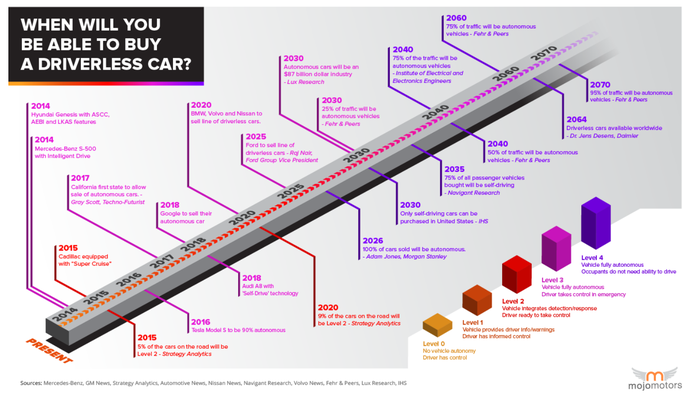
8-16% fuel consumption by simple strategies

Complex cyber-physical uncertainties

- Physical domain
  - ✓ Complex wireless signal propagation and attenuation, wireless interference
  - ✓ Vehicle mobility, driver behavior
  - ✓ Uncertain physical environment: weather, road and vehicle traffic
- Cyber domain: dynamics in wireless networking and platoon control interact with one another during their adaptation to physical dynamics and uncertainties

? Addressing cyber-physical uncertainties in CAV wireless networking, sensing, and control

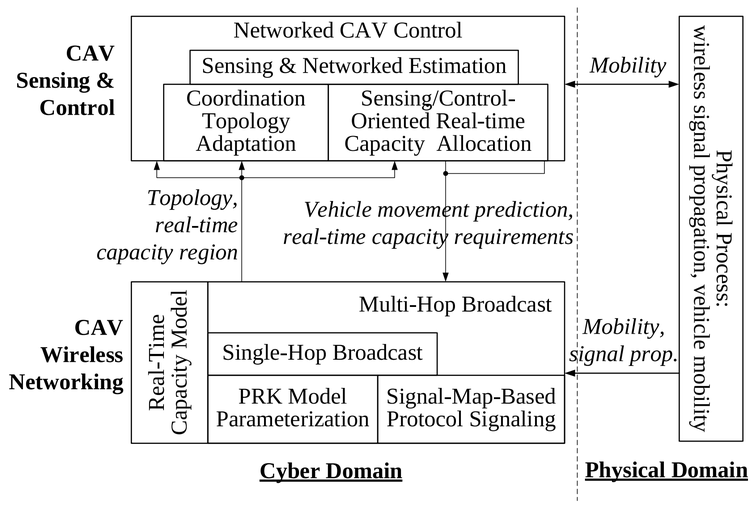
Continuous evolution of applications & networks



? Deployment → R&D

Integrated CAV Wireless Networking, Sensing, and Control

Cross-layer framework for taming cyber-physical uncertainties

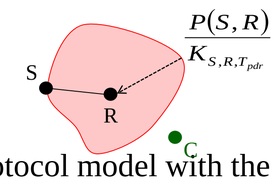


- ✓ CAV sensing and control based on real-time capacity of wireless communication and physical process of vehicle movement
- ✓ Predictable, real-time wireless networking for CAV control
- ✓ Joint optimization and information feedback between CAV control, sensing and wireless networking

Physical-Ratio-K (PRK) Interference Model for predictable interference control

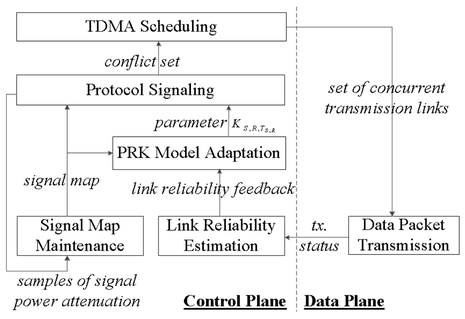
- Given a transmission from node S to node R, a concurrent transmitter C does not interfere with the reception at R iff.

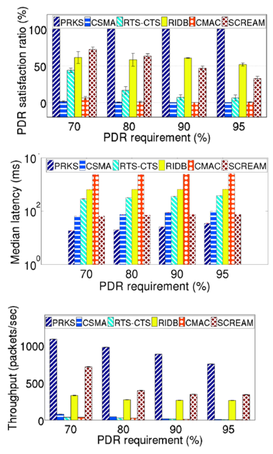
$$P(C,R) \le \frac{P(S,R)}{K(S,R,T_{pdr})}$$



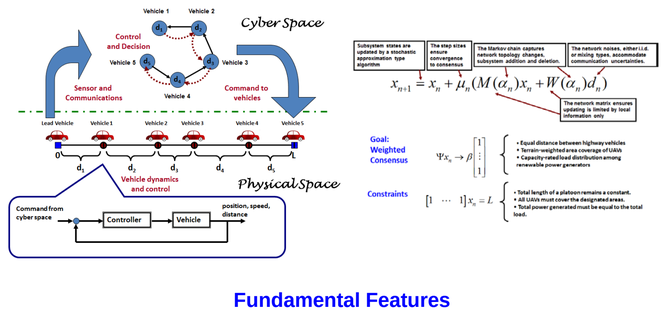
- Integrates the locality of the protocol model with the high-fidelity of the physical model

PRK-based scheduling



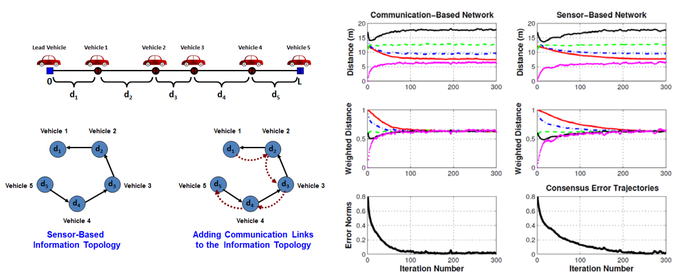


CAV cyber-physical coordination



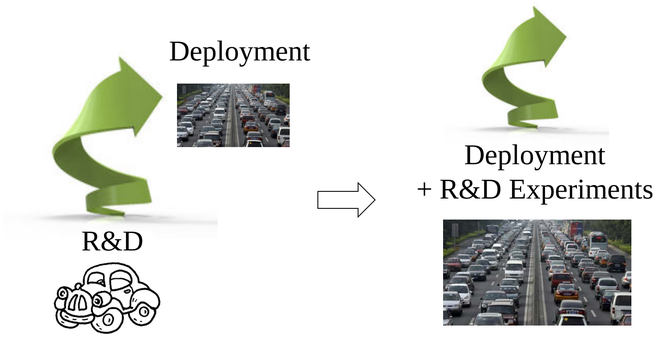
Fundamental Features

1. **The algorithm is convergent, and with post-iterate averaging it achieves asymptotically the Cramer-Rao lower bound.**
2. **It can deal with communication latency, packet erasure, noises.**
3. **It remains convergent under network topology switching, correlated noise, and asynchronous control updating.**
4. **It achieves fast team coordination and formation.**
5. **It restores team formation after large disturbances.**
6. **It restores platoon formation after adding or removing vehicles.**

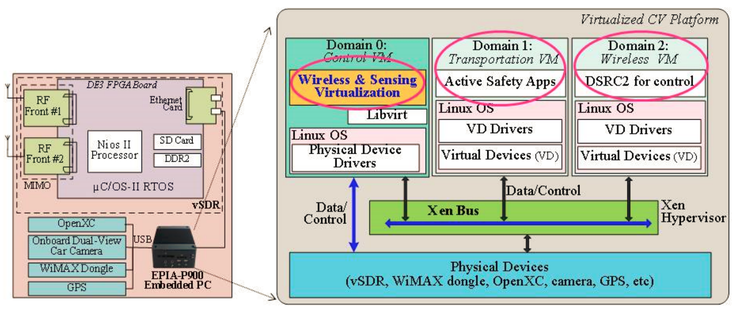


Software-Defined Innovation Platform for Symbiotic Evolution of CAV Applications and Networks

Innovation paradigm shift



Enabler #1: software-defined platform virtualization



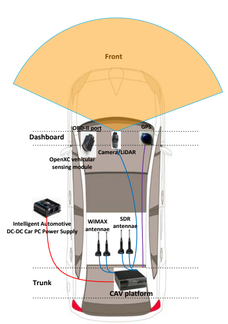
Physical platform — Virtualized platform

Enabler #2: open platform for vehicular sensing

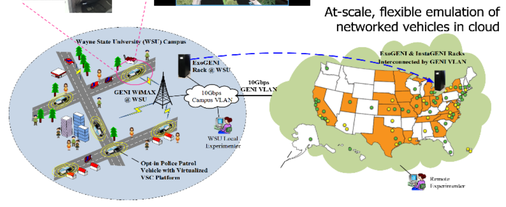
OpenXC-based internal sensing: fuel consumption, emission etc

Camera-based external sensing: surrounding vehicles, pedestrians etc

Wayne State University deployment



Long-term deployment of software-defined platforms on police patrol vehicles



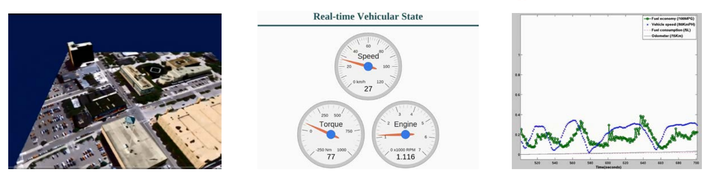
Case study in public safety

Surveillance

Driving safety in emergency response

In US alone, >1 fatality per day;
1 officer killed every six weeks;
$\frac{1}{3}$ killed being innocent bystanders

3D vision & vehicle internal state sensing



At-scale, high-fidelity CAV emulation