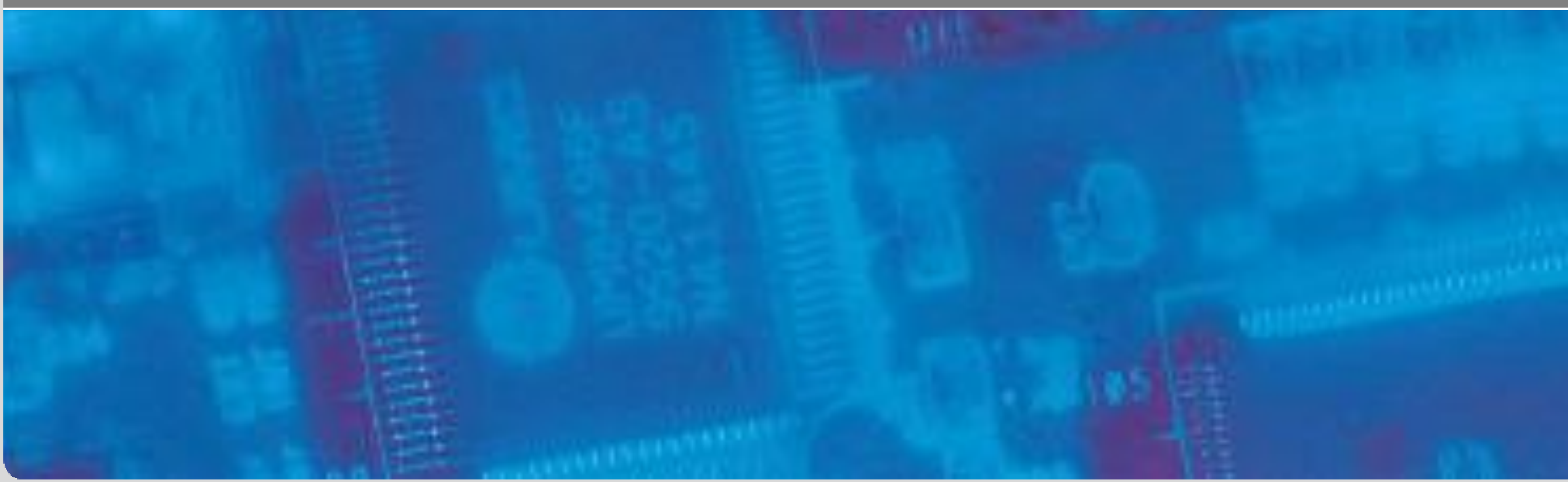
A V2X Message Evaluation Methodology and Cross-Domain Modeling of Safety Applications in V2X-enabled E/E- Architectures

Harald Bucher, Marius-Florin Buciuman, Alexander Klimm, Oliver Sander, Jürgen Becker

Institute for Information Processing Technology (ITIV)



Outline

- Motivation & Challenges
- Fundamentals
- Heterogeneous Co-Simulation Tool-Chain
- V2X Message Evaluation Methodology
  - System Design
  - Cluster-based Message Evaluation Strategy
  - Cost Functions and Acceptance Policies
  - Network Monitoring and Evaluation
- Case Studies: Cross-Domain CACC Evaluation
  - Scenario I - Plattoon Turnaround: Message Savings
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- Summary & Outlook

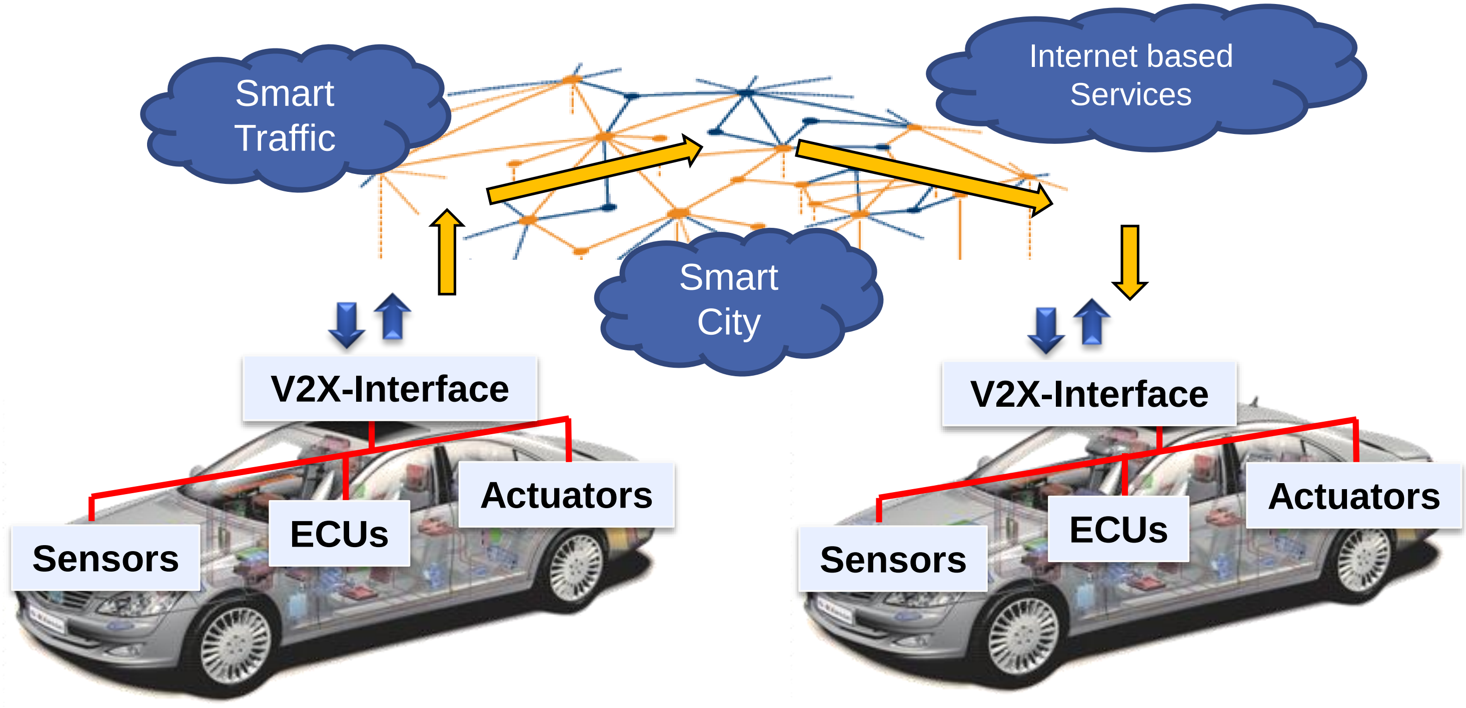
Motivation

- Communication between vehicles as well as infrastructure and environment (V2X Communication)
  - Enlargement of information exchange area beyond line of sight by cooperative applications

Enhancement of Efficiency
- Traffic Flow Management
- Energy Usage
- Energy Preservation
- …

Increasing Vehicle Safety
- Collision Warning
- Adaptive Cruise Control
- Traffic Jam Warning
- …

Challenges



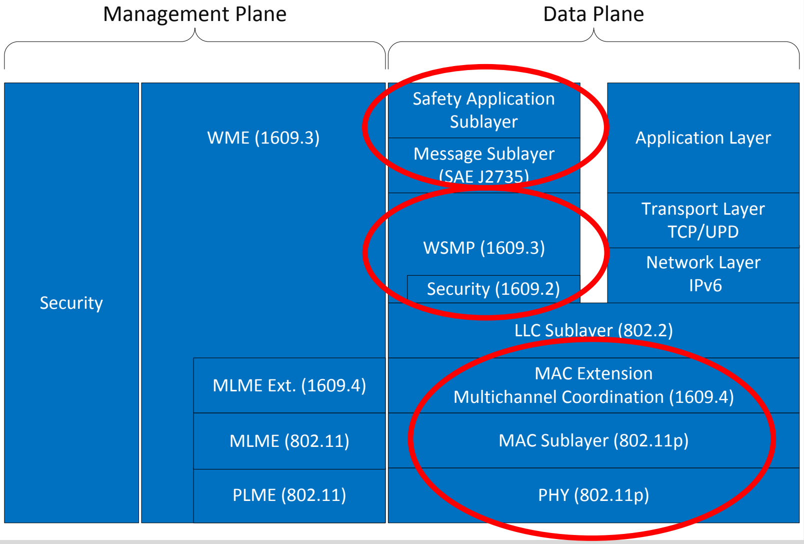
Challenge I: How to holistically model and simulate V2X processing and communication chain?

Challenge II: How to cope with heavy incoming data traffic (up to 2500 Msg/s*) in E/E Architecture and (real-time) safety applications?

* B. Glas et al., „Car-to-car communication security on recongurable hardware," in VTC Spring'09, 2009.

Fundamentals – V2X Communication

- Vehicles regularly broadcasting their state as *beacons* or *SAE Basic Safety Message (BSM) at 2-10Hz*
- New Protocol and Message Type with minimized protocol overhead optimized for V2X and safety applications
  - PHY & MAC based on ordinary Wi-Fi with some extensions
    - One Control Channel (CCH) for Safety Messages and Beacons
    - 4-6 Service Channels for non-safety traffic
  - IEEE WAVE Short Message Protocol (WSMP)
  - IEEE WAVE Short Message (WSM) contains
    - Service Identifier (PSID)
    - Priority
    - Channel Number
    - Receiver Address
    - Payload (e.g. BSM)
    - …



Solution Challenge I: Heterogeneous Co-Simulation Tool-Chain*

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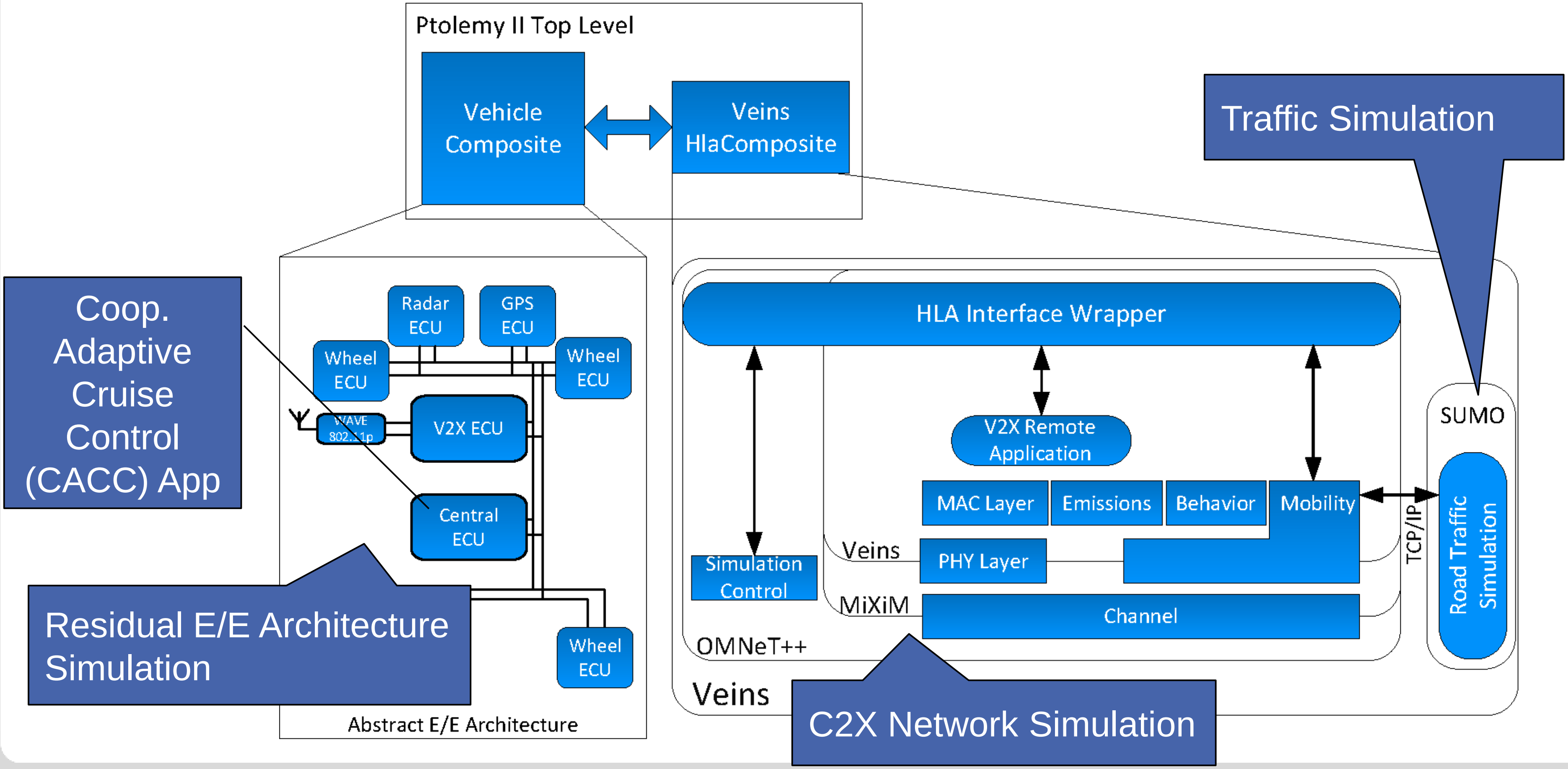
- Framework based on Ptolemy II as central heterogeneous manager tool and High-Level Architecture (HLA) as simulation backbone
- Used for Case Studies



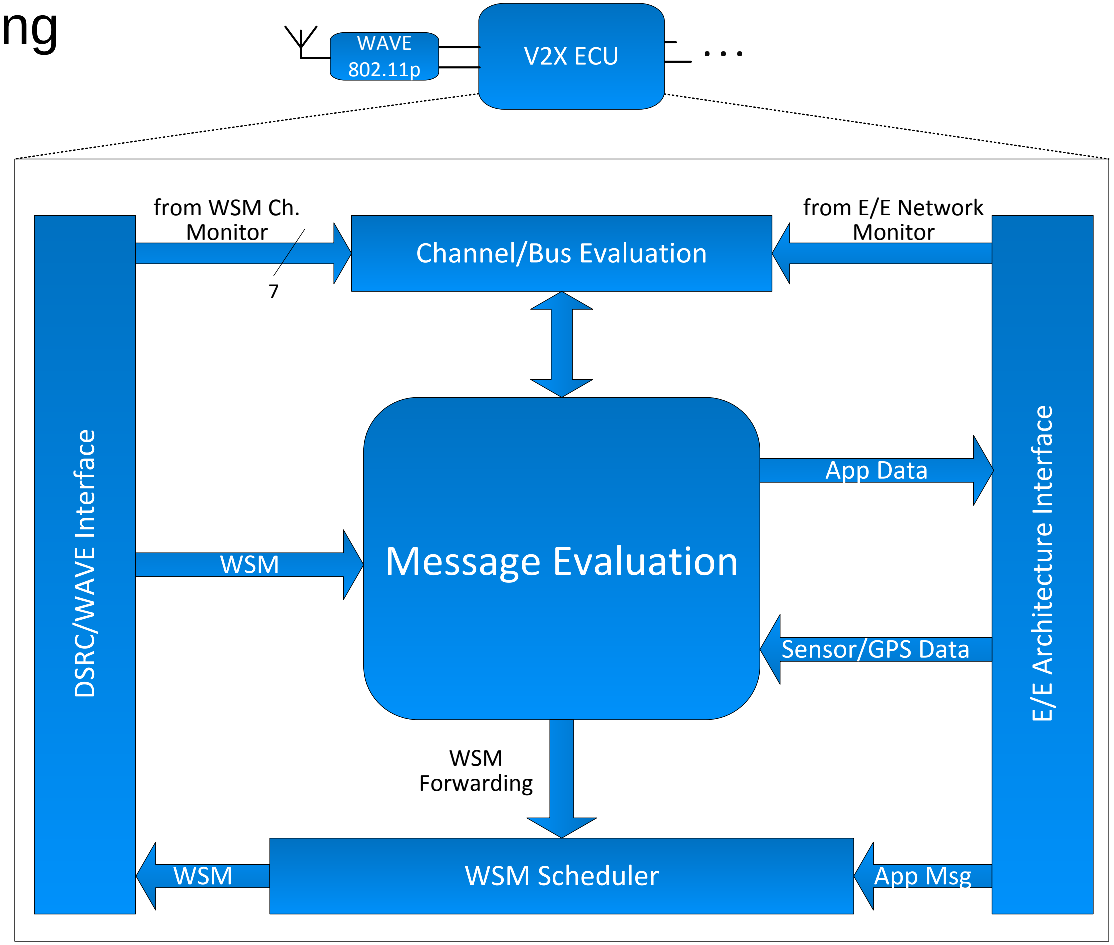
* C. Roth, H. Bucher et al.,"A Simulation Tool Chain for Investigating Future V2X-based Automotive E/E Architectures," in Embedded Real Time Software and Systems (ERTS²), 7th European Congress on, Feb. 2014, pp. 1739-1748.

Solution Challenge II: Proposed V2X Message Evaluation Methodology for Safety Applications

- Goal: Reduce internal E/E processing efforts and network traffic by discarding irrelevant V2X messages
- Idea
  - WAVE compliant methodology
    - Needs only beacon‘s *WSM header and payload* data for evaluation
  - *Cluster-based* evaluation reduces evaluation complexity
  - Adaptive *Acceptance Policies* based on network and vehicle state monitoring

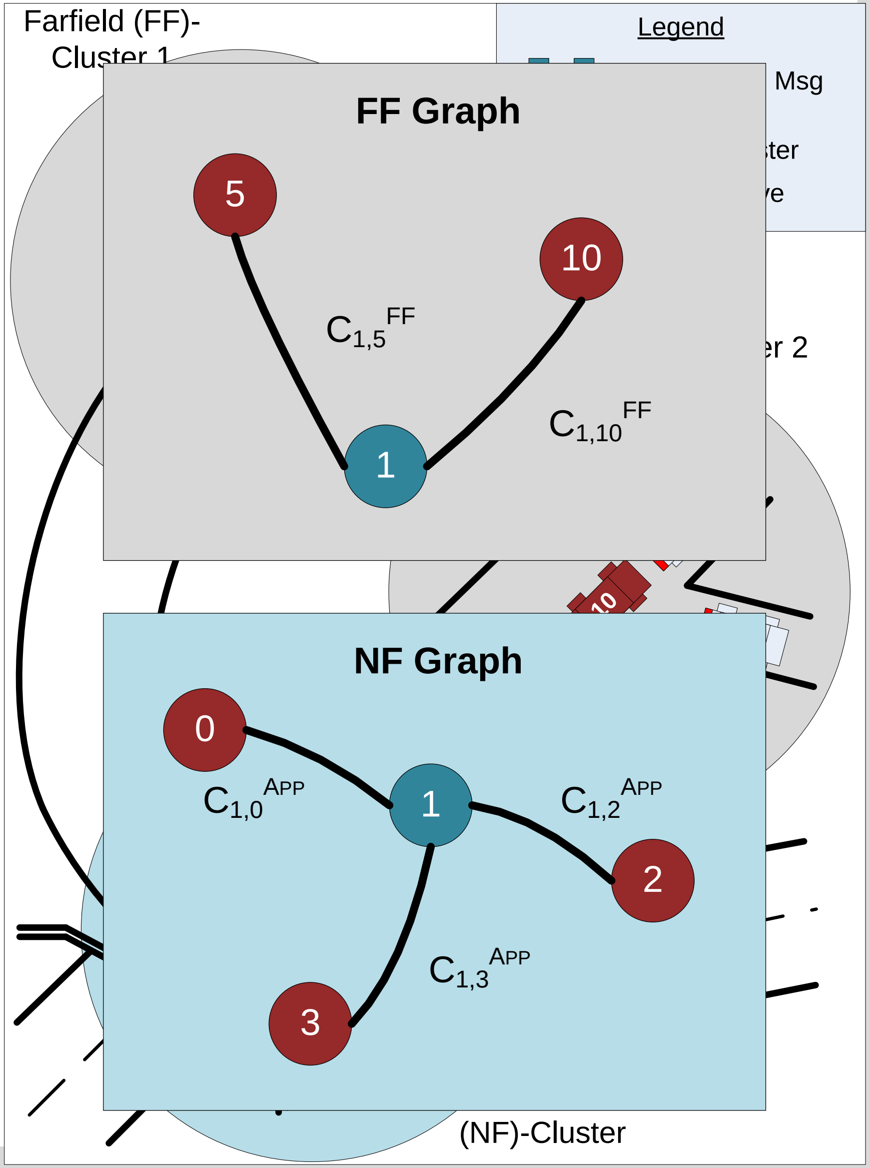
V2X Message Evaluation System Design

- Intelligent Gateway inside V2X ECU for evaluation based on incoming beacons as well as local sensor data and network/vehicle state monitoring



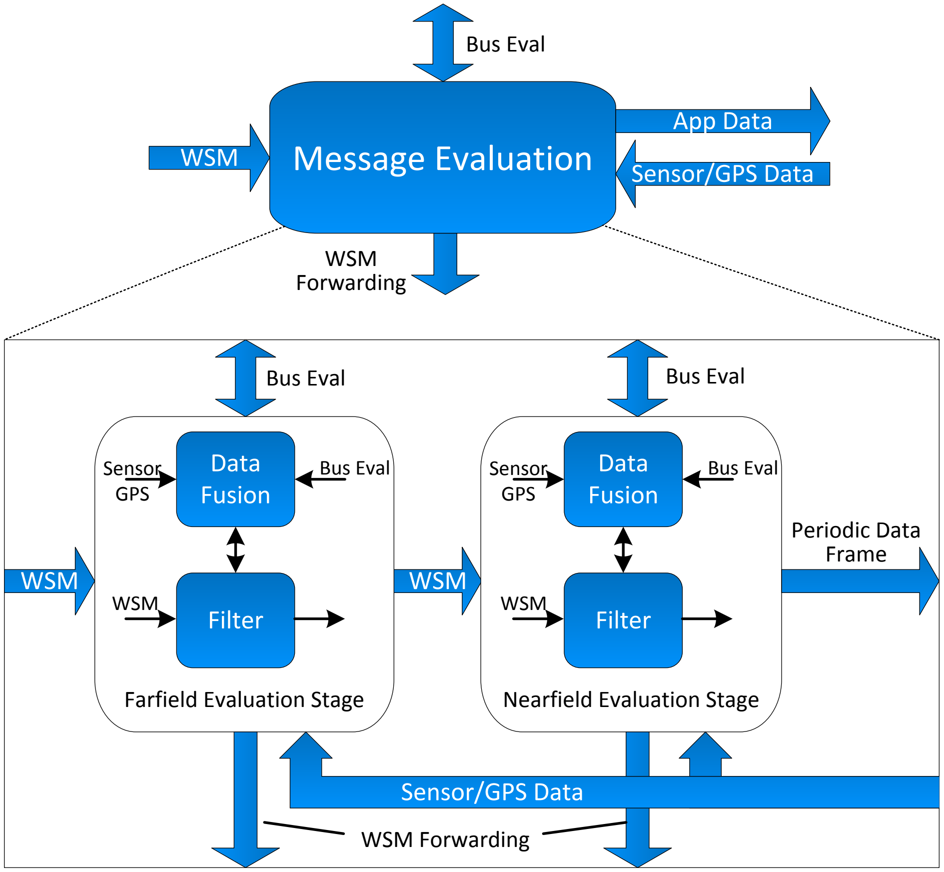
Cluster-based V2X Message Evaluation

- Create virtual traffic view
- Classification into *Farfield* and *Nearfield* Networks (FFN / NFN)
  - Vehicles within NF range are potentially safety-critical
  - Vehicles outside NF range are clustered
    → FF Master/Slave with own NF range (First-Come-First-Serve)
    → inherent prefiltering of slaves
- Weighting of relations between nodes (vehicles) with cost-functions
  - Generic FF function
  - individual application-specific nearfield functions



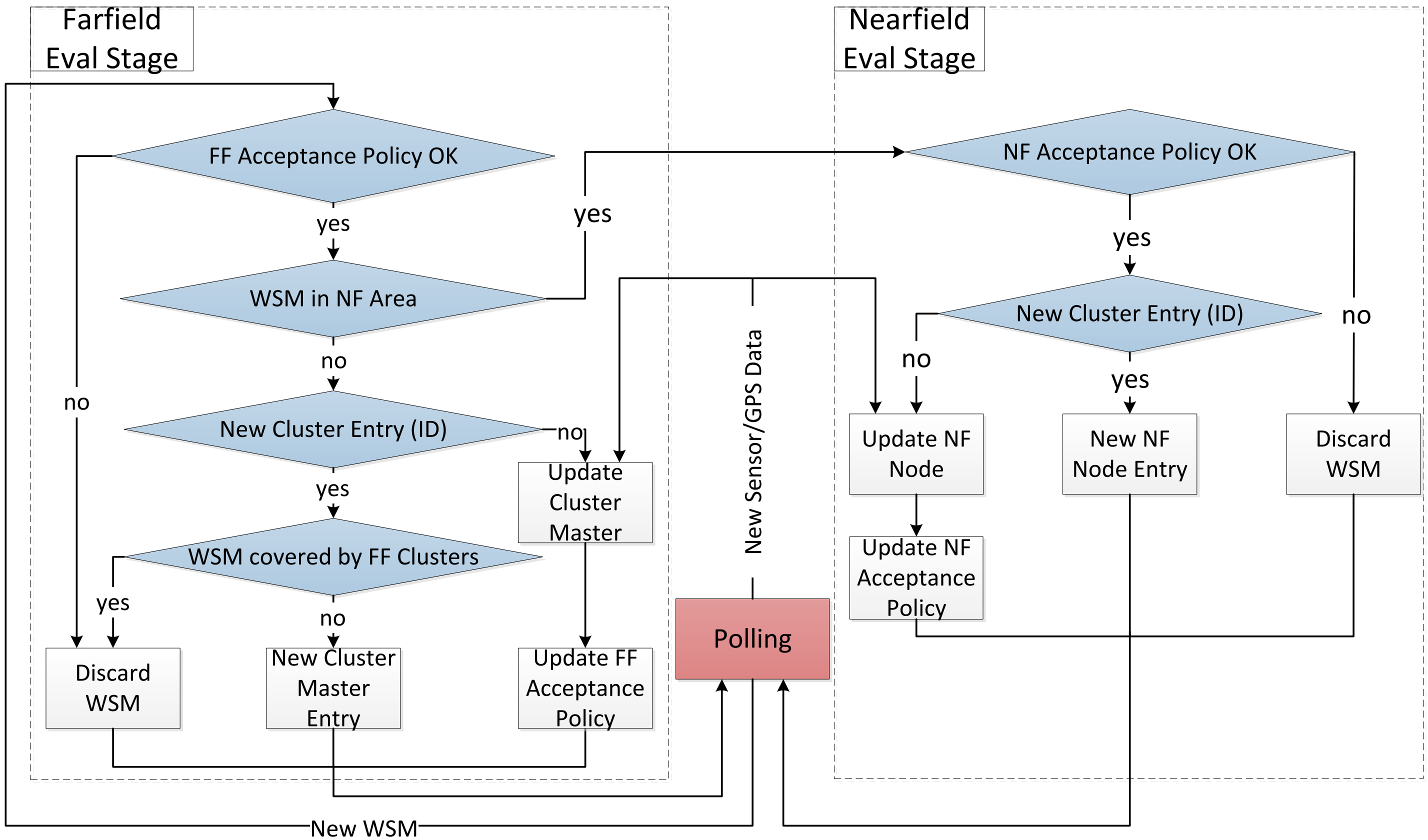
Refined Cluster-based V2X Message Evaluation System

- NF and FF Stage composed of
  - Static *Filter* Unit
  - Dynamic *Data Fusion* Unit
- Filter Unit
  - Compares current *Acceptance Policies* with incoming WSM data
- Data Fusion Unit
  - Determines *Acceptance Policies* based on network monitoring and vehicle state
  - Forwards incoming event-driven WSMs based on PSID
  - Calculates cost functions C^{FF} and $C^{NF(CACC)}$
  - Periodic forwarding of most relevant NF data frames to destination application (in this work CACC)



Hybrid Clustering and Hierarchical Evaluation Strategy Procedure

- Update FF/NF Node: Updates mobility information between local vehicle v_i and remote vehicle v_j and calculates cost functions $C_{i,j}^{FF}\ \forall\, j \in FFN$ and $C_{i,j}^{CACC}\ \forall\, j \in NFN, j \neq i$
- Update FF/NF Accpetance Policy: Update Acceptance Policies A_{FF} and A_{NF} based on cost function and vehicle state as well as network utilization



Cost Functions and Acceptance Policy Sets

- FF cost function detects hot-spots and serves as premature warning

$$C_{i,j}^{FF} = a * compDriveDir() + b * psidEval() + c * normDistance() + d * compRelPos(),$$
$$\mathrm{a} = c = 0.1, b = 0.5, d = 0.3 \ and \ a + b + c + d = 1.0$$

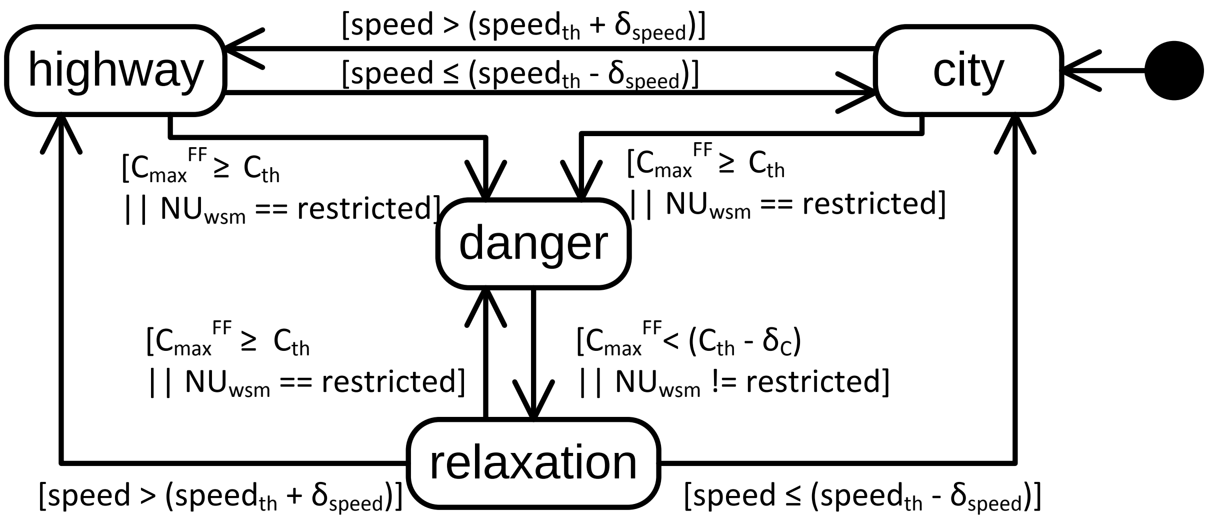
- NF cost function for detection of the leading vehicle for CACC app.
  - CACC Frame Rate $\lambda_{CACC} = 10\mathrm{Hz}$

$$C_{i,j}^{CACC} = compDriveDir() * normDistance() * compRelPos(), [0.0,1.0]$$

- Individual *strong* and *weak Acceptance Policies* for FF and NF
  - $A_{FF} = \{ID, psid, prio, age, range\}$
  - $A_{NF} = \{prio, age, range\}$

Acceptance Policy Adjustments

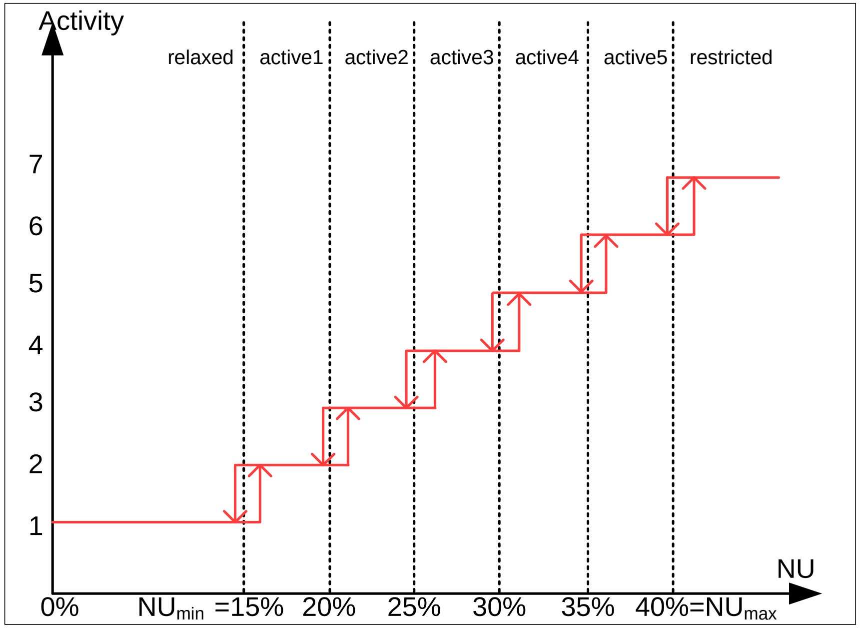
- A_{FF} are mainly determined by *Driving State FSM*



- A_{NF} must not depend on FSM but mainly on internal network utilization (NU) because of the prefiltering in FF stage
  - High network utilization results in *strong* policies in order to relax internal network traffic for safety critical applications

Network Monitoring and Evaluation

- Protocol independent metric for monitoring
  - Based on byte-rate B_{wsm}, B_{ee} measured over time interval T and nominal byte-rate N_{wsm}, N_{ee}
- Smoothed linearly*
  - $NU_x(\tau) = 0.5 * NU_x(\tau - 1) + 0.5 * \frac{B_x}{N_x},$
    $x = \{wsm, ee\}$
- Discretized into 7 NU activity states*



* "Intelligent Transport Systems (ITS); De-centralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part," ETSI TS 102 687 V1.1.1, Jul. 2011.

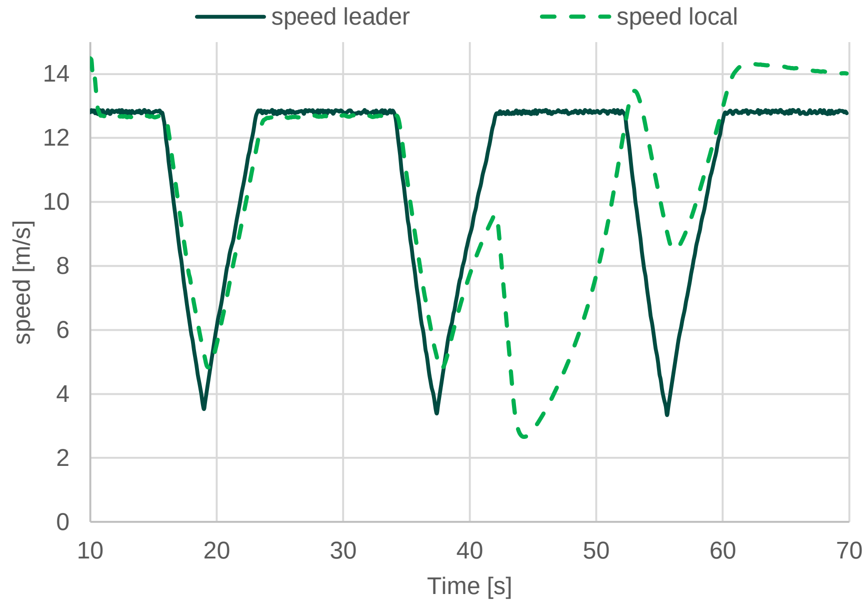
Case Study: Cross-Domain CACC Evaluation

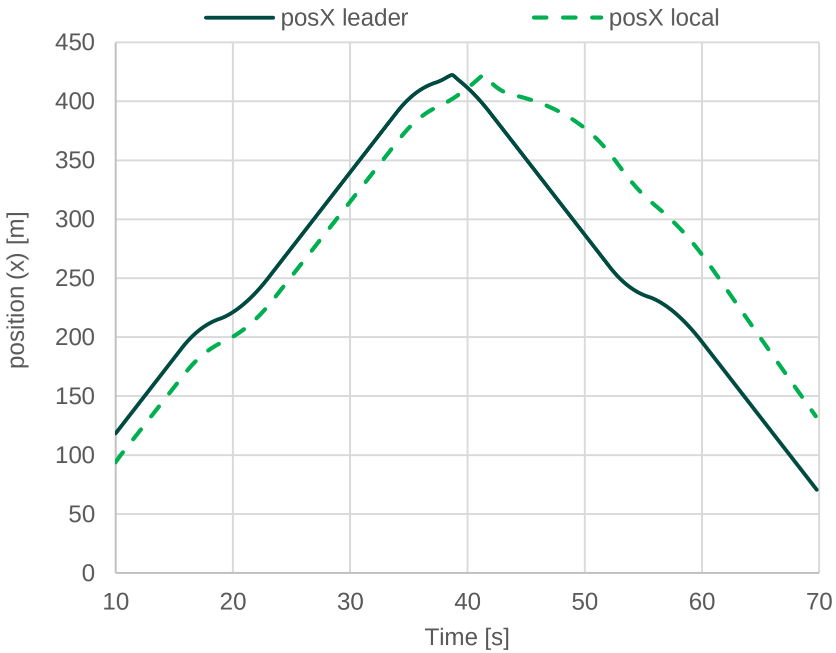
- Simulation Setup
  - Plattoon following scenario
  - Approaching intersections every *200m*
  - OMNeT++
    - Transmit Power: *20 dBm*
    - WSM Channel: *CCH*
    - WSM Bitrate $N_{wsm} = 6\ Mbps$
    - Beacon Rate: *10Hz*
  - SUMO
    - Vehicles: *30*
    - Max. Speed: *~50 km/h*
    - Mobility Update Rate: *10Hz*
  - Message Evaluation (Ptolemy)
    - Sensor Update Rate: *10Hz*
    - $N_{ee} = 500kbps$
    - CACC Frame Rate λ_{CACC} = *10Hz*
    - Acceptance Policies: *cp. Table 1*

Table 1: Acceptance Policy Specification

A_{FF}		
	weak	**strong**
PSID	all	safety related
prio	all	prio(BSM)
range (x,y,z)	300m	150m
age	1.0s	0.5s
A_{NF}		
	weak	**strong**
prio	all	prio(BSM)
range (x,y,z)	300m	100m
age	0.5s	0.2s

Results Scenario I: Plattoon Turnaround





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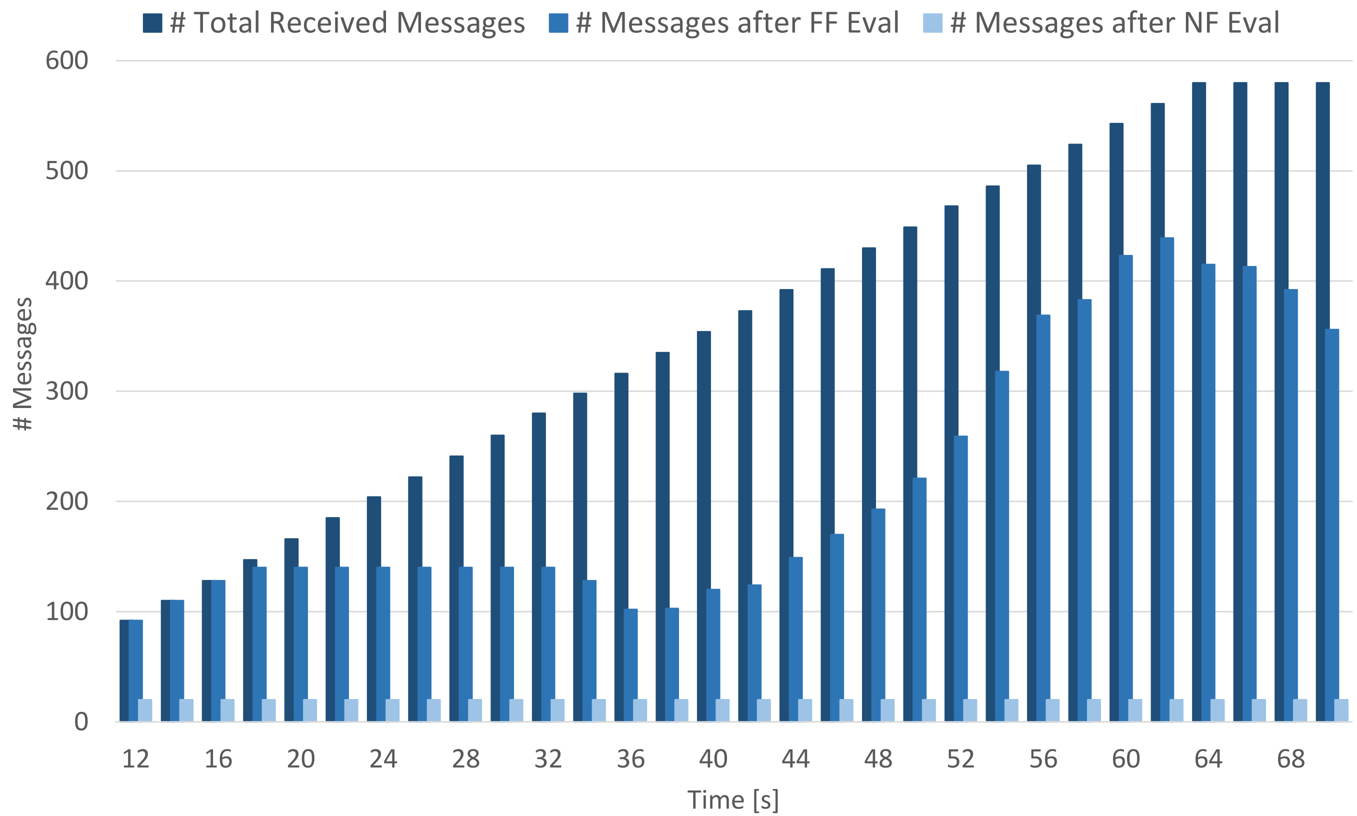
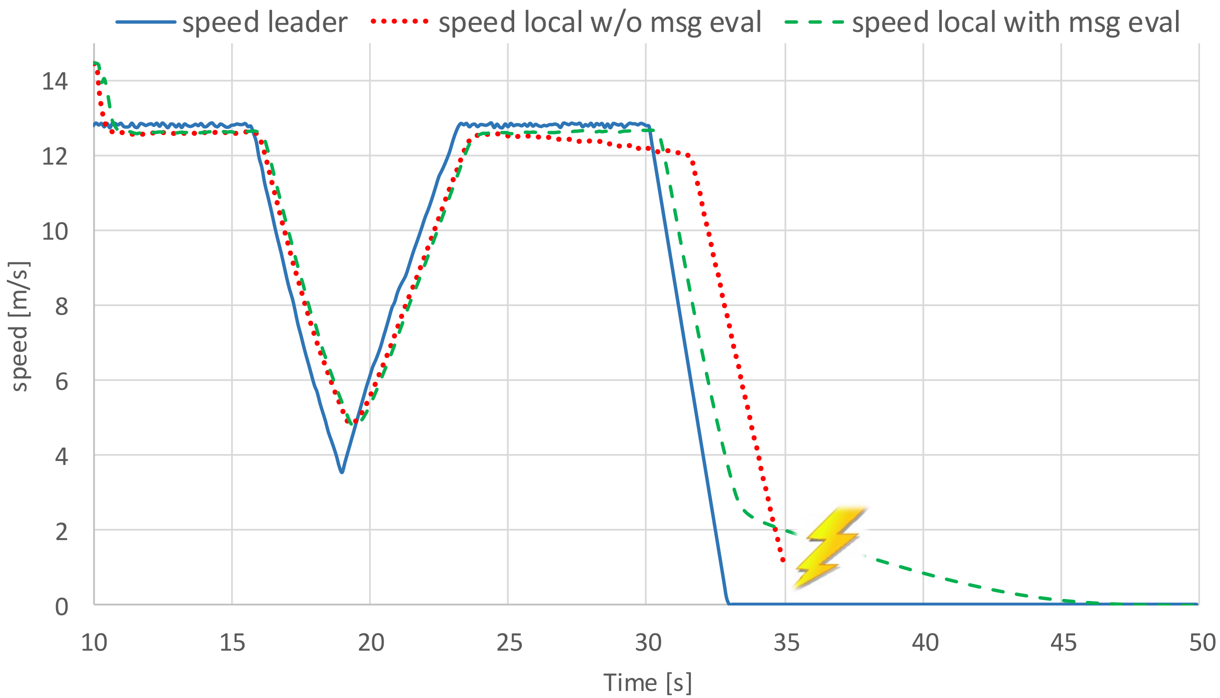


- Message Saving after FF Eval: **Max. 69,3% and 37,0% in average**
- Overall Message Saving after NF Eval: **Max. 96,6% and 92,7% in average**

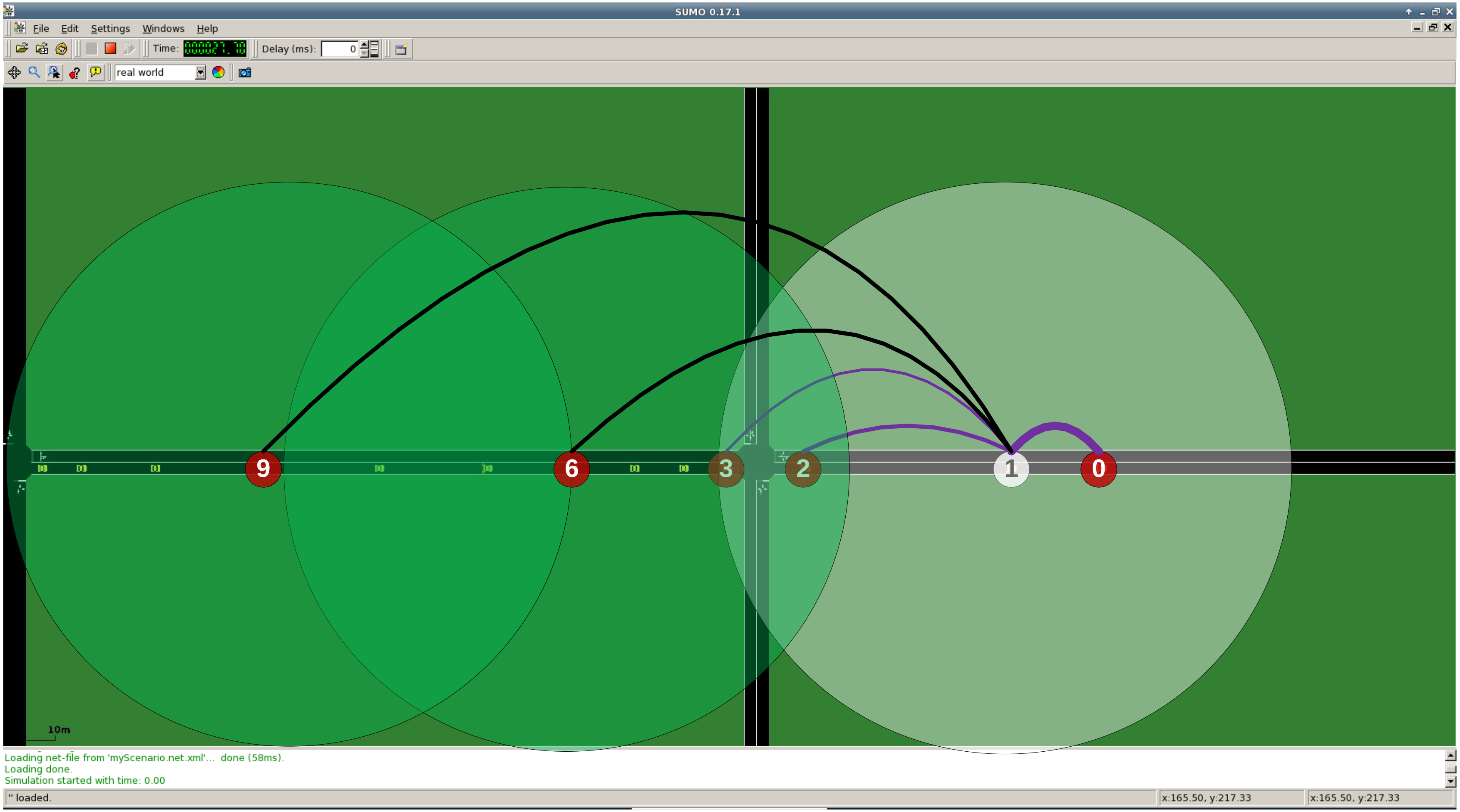
Results Scenario II: CACC Verification

- Broke down leading vehicle after *30s*
  - Event-Driven warning with PSID `0x8005` sent out → *strong* A_{FF}
- Modeled worst case reception latency per beacon inside E/E architecture model: *10ms**
- Comparison of CACC behavior w/ and w/o Message Evaluation



* SAE Standard for Dedicated Short Range Communications (DSRC) Message Set Dictionary, SAE Std J2735, Nov. 2009.

Example Simulation Snapshot



Summary

- Presentation of a WAVE compliant V2X Message Evaluation Methodology
  - Hierarchical vehicle clustering strategy
  - Vehicle and network (internal/external) state monitoring (Cost Functions)
  - Adaptive Acceptance Policies

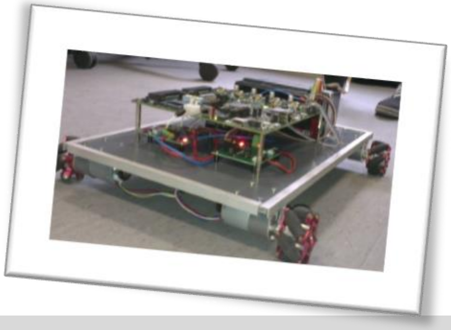
- Modeled inside V2X ECU together with abstract E/E architecture components reducing internal network traffic and message processing efforts

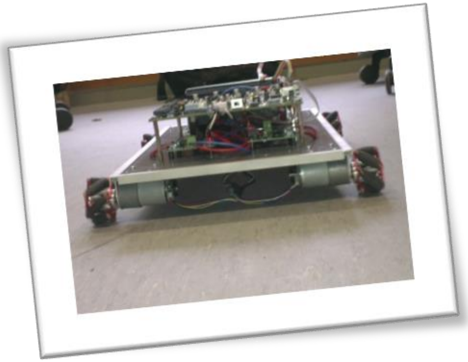
- Model-based cross-domain evaluation of CACC application with co-simulation framework
  - Taking into account internal processing and communication latencies
  - Enables early and deterministic exploration and evaluation of (abstract) E/E architectures in V2X scenarios

- Significant reduction of V2X messages need to be processed during run-time
  - 92.7% in average in reverse traffic scenario
  - Accident-free CACC behavior in case of worst-case WSM latencies and broke down leading vehicle

Outlook

- Investigation of more complex traffic scenarios
- Deeper analysis of acceptance policies
- Analysis of power/energy consumption reduction of signature verification modules by the approach
- Implementing the approach on real target platforms
- Validation of the approach and CACC scenario by means of robot prototypes





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Thank you very much for your attention!