Realistic testing of operational radio communications from and to vehicles in virtual electromagnetic environments

OTA in VEE

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Challenges of real-life testing C2X

Propagation environment
- Multipath
- Delay-, angular-, and Doppler-spread
- Large-scale and small-scale effects
- Interaction of EM field and antennas

Radio environment
- Variety of transmission standards frequencies, modulation, coding, access scheme
- Multiple users, interference

• Performance depends on dynamically changing, complex scenarios in terms of traffic and radio environment
• Mixture of infrastructure and ad-hoc based access
• System level performance assessment
• Holistic approach: including both vehicle and driver response (“driver in the loop”)
Test Drives vs. Virtual Reality

“Virtual reality” is a computer generated environment that emulates reality

- Acoustics, music and noise
- Visual representation
- Human interaction

Radio drive tests comprise:

- Installed performance (system level test)
- Driver in the loop
- Realistic and live environment

Radio drive tests:

- Likely too expensive and not reproducible
- Depend on existing infrastructure and existing standards
- Insufficient for certification
- Restrictions of ethical and legal extent
Radio drive test goes virtual

Emulating multipath, multiple users, and interference in a shielded environment

Model of vehicular radio environment

Wave field generation in anechoic chamber (stationary vehicle)
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Over-The-Air testing in Virtual Electromagnetic Environments

- EM field emulation in anechoic chamber
- System level test, installed performance of antennas and vehicle
- Controllable and reproducible
- No interference to and from deployed systems (shielded environment)
- Testing vehicles in new, prospective, or foreign radio access networks
- Arbitrary scenarios: ”radio crash test”/critical interference, dynamics, ”what if”
- OTA\textsubscript{in}VEE transparent for radio access technology
- Closed-loop: dual directional

Example: OTA\textsubscript{in}VEE set-up for LTE/LTE$^+$

source: Fraunhofer IIS FORTE
OTA

Balance of effort: realism vs. complexity

- Realistic emulation of radio wave fields (w.r.t. use of resources)
- Closed-loop performance (up- and down-link, e.g. for protocol or multi-hop)
- Multiuser scenarios (ad hoc!)
- (Massive) Interference

Minimum requirements for emulation realism:

- Dynamics of time variance, incl. large-scale fading (“road movie”)
- Balancing RF environment complexity with test scenarios on higher layers
Accurate Wave Field Synthesis (WFS) requires huge resources:
- Any field linearly decomposed into plane wave components
- 5 m class vehicles @6 GHz and 3-D: thousands of antenna ports
- High connectivity: many user/interference sources
- One multi-input channel emulator per antenna port: costs ~20-40 T€
- Closed-loop: additionally, the same in reception (“reciprocal” process)
OTA_inVEE: Balance of effort

Two implementation options

Discriminate between coherent and power/signature transmissions, with different emulation strategies

• Coherent
  – phase of incident fields important
  – direction of incident fields important
  – related to antenna performance w.r.t. MIMO, diversity
  – transmitted information important

• Power/signature (representation of increasing sophistication)
  – "best bang for bucks"
  – in-band angular spectral density (spatially coloured noise)
  – system mimicking:
    temporal (frame) structure
    modulation characteristics (nonsense bits allowed)
  – user activity pattern, etcera

• In both cases, still scenario-specific, with multi-user influence
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Coherent emulation: Two-stage or hybrid OTA

- Devices-under-Test exceeding sweet spot size
- Combining synthesis with reception/transmission through antenna patterns, in real-time
- Test on bench over cables connected to system I/O
- Requirements
  - antenna patterns known (not just 2D cuts)
  - antennas separable: access to connectors loading/matching
  - still sufficient signal processing power
- Disadvantages
  - EMC issues: e.g. self-interference locked out
  - tricked out by antenna adaptivity: tuning, matching
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Power spectrum/signature emulation

- In anechoic chamber
- System and scenario dependent sophistication
- Split fields into
  - Communication transmissions (multi-user)
  - Interference
  - Noise
- Discretise angular power spectrum:
  - No synthesis, fixed radiation directions
  - Multipath instead of angular spread
  - Hope for wide antenna patterns 😊
- Temporal, spectral signature emulation
  - Communications: transparent, with fading
  - Interference: depends on sophistication of System-under-Test
  - Noise: spectrally and angularly coloured noise

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OTA in VEE Lab at TU Ilmenau

TU Ilmenau VISTA
Virtual road project

2014
Anechoic room
Turntable
Dynamometer/
per wheel drive
Measurements C2X
Channel models C2X
FhG FORTE: 2-stage

2015
Antenna patterns
Emulation
FhG FORTE:
WFS@6GHz
Conclusions

OTAinVEE:

- **System level test: antennas, vehicle, and environment:**
  - Alternative to drive tests
  - Controllable and reproducible
  - No interference from and to outside world
  - Transparent to radio access technology
  - Emulation of arbitrary scenario dynamics, incl. “what if”

- **Two implementations envisaged**
  - Two-stage for accurate wave fields, but vehicle is modelled
  - Power/signature emulation for large DuT, but simplified wave fields

- **Test scenarios**
  - Channel dynamics (large-scale effects included)
  - Balanced over layers, crowded when needed