Simulations vs. Emulations for Evaluating Cooperative ITS Applications for Sustainable and Safe Mobility

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Acknowledgments

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- Colleagues of the iTETRIS Consortium, in particular:
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  - Navid Nikaein, Raymond Knopp, among others...

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Sustainable and Safe Mobility?
Sustainable and Safe Mobility??

- **Visionary Phase: GM Futurama**
  - Build a nation-wide transportation network
  - Car-to-Car communication for secured and fast mobility…
  - Yet: Capacity of Road Infrastructure grows slower than traffic

- **The safe and sustainable mobility conundrum:**
  - **Flow Theory:** \( \text{Flow} = \text{Density} \cdot \text{Speed} \)

  - **Safety Authority:** Drive Safe = Drive Slower
  - **Transportation Authority:** Sustainable Mobility = Roads used to their maximum capacity

- **Unsustainable Mobility**
  - Reduced Flow
  - Increased Density

- **Unsafe Mobility**
Sustainable and Safe Mobility??

The safe and sustainable mobility conundrum:
- **Flow Theory:** \( \text{Flow} = \text{Density} \cdot \text{Speed} \)

Directions?
- Increase Capacity of Road Infrastructure? [No]
- Reduce Flow? [Yes]
- Keep Speed? [Yes]

ITS Applications
- Optimize the usage of road infrastructure
  - Cooperative navigation
  - Multimodal Transportation
- Allows to drive fast and safe by foreseeing danger
Objectives for Intelligent Transportation Systems

- To avoid this...
Evaluating ITS Applications

- Optimally, through large field operational tests!

- Limitations:
  - Safety:
    - cannot test when the safety of drivers or other vehicles are at risk
  - Scalability
    - Need to evaluate over a city-wide and over a long time period
  - Flexibility
    - Re-play
    - Modification
    - …

- Simulations and Emulations are a natural option
  - Simulators/Emulators are ‘just’ tools
  - Challenge:
    - Appropriate models
    - Close-to-Reality Scenarios
    - Flexible Methodology
## A Brief Comparison

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Scenario Setup</th>
<th>Abstraction / Modeling</th>
<th>Reproducibility</th>
<th>Scalability / Costs</th>
<th>Limitation</th>
<th>Net Traffic &amp; Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analytical</td>
<td>+</td>
<td>-</td>
<td>+++</td>
<td>+++</td>
<td>Complexity</td>
<td>Abstracted/Modeled</td>
</tr>
<tr>
<td>Simulation</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
<td>Abstraction</td>
<td>Modeled</td>
</tr>
<tr>
<td>Emulation</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>CPU/Cost</td>
<td>Modeled / Real</td>
</tr>
<tr>
<td>Real Testbed</td>
<td>+++</td>
<td>NA</td>
<td>-</td>
<td>-</td>
<td>Cost</td>
<td>Real</td>
</tr>
</tbody>
</table>

**Note:**
- Analytical: High Complexity, Modeled
- Simulation: Modeled
- Emulation: Modeled / Real
- Real Testbed: Real
Classification of the Validation Platforms

**Analytical**
- UML
- FreeMat
- IDL
- Matlab
- SciLab
- Octave

**Simulation**
- Sinalgo
- NetSim
- GloMoSim/Qualnet
  - NS-3
  - Opnet
  - Omnet++

**Emulation**
- NS3
- NistNEm
- CORE
- USPR2
- WARP
- CMU-DSR
- ORBIT
- OAI

**Real Testbed**
- PlanetLab/OneLab
- NITOS
- GnuRadio
- WARP
- ORBIT
- Sundance, BEE2, WiTestLab
- USPR2
- OAI

Scalability | Reproducibility | Applicability
--- | --- | ---
Abstraction Level | | Realism Level
ITETRIS OPEN SOURCE SIMULATION PLATFORM
The iTETRIS Project

Main Objectives

- Build an integrated wireless and road traffic simulation platform
- For large-scale evaluation of cooperative road traffic management solutions

Consortium and Acknowledgements:

ICT-FP7 STREP project (Call 2)

- Strategic Objective: ICT for Cooperative systems
- Website:  http://www.ict-itetris.eu
The Open-Source iTETRIS Platform

- UC A: Traffic Jam Ahead Detection
- UC B: Traffic Time Estimation
- UC C: Emergency Vehicle & Bus Lane Management
- UC D: Request-Based Personalised Navigation
- UC E: Regulatory & Contextual Speed Limit Information
- UC F: Event Based Traffic Condition Notification

ns-3

iCS

- Synchronization
- Position Update
- Message Exchange
- Application / Information Support facilities:
  - Mobile Station Facilities
  - Location Referencing Facilities
  - Message Facilities

SUMO

Source: M Roeckl, DLR, iTETRIS 2011
CHALLENGES FOR SIMULATING ITS APPLICATIONS
Challenge 1: Calibrated Traffic Scenarios

- Simulation of Urban Mobility (SUMO)
  - Open-source microscopic traffic simulator
  - Available: sumo.sourceforge.net

<table>
<thead>
<tr>
<th>Function</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microscopic Model</td>
<td>Krauss Model</td>
</tr>
<tr>
<td>Macroscopic Model</td>
<td>O-D Matrix; weight-based shortest path</td>
</tr>
<tr>
<td>Extensibility</td>
<td>online APIs for route change, traffic lights, infrastructure retrieval, interactions with vehicles</td>
</tr>
<tr>
<td>Traffic Light</td>
<td>Embedded and through APIs</td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
</tbody>
</table>

iTETRIS-specific Features

- Scenarios (Bologna)
  - Validated Urban (Pasubio-Costa);
  - Suburban (Irnerio);
  - Highway
- Emission Model        | HBEFA [10]                                                |
- Noise Model           | HARMONOISE [15]                                           |
Calibrating Scenarios: Bologna

- Calibrating Traffic Scenarios in SUMO
  - Digital Map (up to the lane level)
  - Traffic Volumes on Road Segments
  - Turning Ratio at intersections

Coordinates: 120608 Location: 1100 BURRARD ST
Calibrated Scenarios in iTETRIS

**acosta**
- 179 nodes, 182 edges
- 8888 vehicles in total
- ~550 vehicles max.

**pasubio**
- 135 nodes, 111 edges
- 8681 vehicles in total
- ~1400 vehicles max.

**joined**
- 309 nodes, 271 edges
- 11079 vehicles in total
- ~950 vehicles max.

**irnerio**
- 410 nodes, 749 edges
- 10367 vehicles in total
- ~900 vehicles max.

**ringway**
- 1210 nodes, 2216 edges
- 19987 vehicles in total
- ~2000 vehicles max.

**highway**
- 1140 nodes, 2157 edges
- 46026 vehicles in total
- ~2500 vehicles max.
Challenge 2: Vehicular-specific Heterogeneous Communication Simulator

- **Network Simulator: ns-3**
  - [http://www.nsnam.org/](http://www.nsnam.org/)

- **Good general network simulator**
  - Not adapted to vehicular-specific communication and protocols
  - Added the ETSI ITS protocol stack

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Intelligence in the Communication Stack

Position-based Geographic Routing

Heterogeneous Access Technologies

Communication Facilities
- Communication Technology
- DENM
- CAM
- DTN Convergence Layer

Network
- BTP
- TCP
- UDP
- IP

Access Technologies
- 802.11p
- WiMAX
- DVB-H
- UMTS

Channel
- V2V and V2I Fading Channel
Optimal Communication Technology Selection

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Vehicular Channel Models

### ITSG5A / 802.11p / DSRC

<table>
<thead>
<tr>
<th></th>
<th>Urban</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V2V</strong></td>
<td>WINNER B1 - Urban microcell</td>
<td>Cheng &amp; Stancil</td>
</tr>
<tr>
<td><strong>V2I</strong></td>
<td>WINNER B1 - Urban microcell</td>
<td>WINNER D1 - Rural</td>
</tr>
</tbody>
</table>

### Cellular

<table>
<thead>
<tr>
<th></th>
<th>Urban</th>
<th>Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WiMAX</strong></td>
<td>WINNER C2</td>
<td>WINNER D1</td>
</tr>
<tr>
<td><strong>UMTS</strong></td>
<td>WINNER C2</td>
<td>WINNER D1</td>
</tr>
<tr>
<td><strong>DVB-H</strong></td>
<td>Okumura-Hata Urban and Suburban</td>
<td>Okumura-Hata Rural</td>
</tr>
</tbody>
</table>

- **WINNER C2** - Urban macro-cell (2-6 GHz)
- **WINNER D1** - Rural macro-cell (2-6 GHz)
- **Okumura-Hata** - Macro-cells (100 - 1500 Mhz)

Source: J. Gozalvez, R. Bauza, M. Rondinone, M. Sepulcre, UMH, iTETRIS 2011
Impact of the iTETRIS Fading Models on Network Connectivity

- Close-to-Reality Fading Models
  - Effects of non-LOS in urban settings
  - WINNER B1 model for WAVE propagation

Source: Y. Lopez and J. Leguay, Thales, iTETRIS 2011
Challenge 3: Bi-directional Interaction

- Fundamental Difference between ITS and standard wireless networks
  - Mobility is not a perturbation
  - Mobility IS the application
    - We need to model it
    - We need to control it
Challenge 4: Modeling and Integrating ITS Application

- Applications are independent entities
  - Modeled as third module

- Application Simulator:
  - Lightweight module
  - Open APIs
  - Provided for C++, Python and Java
Challenge 5: Interaction between ITS Applications and other Modules

- Subscription are used to send or retrieve data to modules
  - Portability and extensibility are required

- Developed six generic open APIs
  - TLV (Type-Length-Value) Encoding

- Subscription are used to send or retrieve data to modules
  - Portability and extensibility are required

- Developed six generic open APIs
  - TLV (Type-Length-Value) Encoding
SOME APPLICATION RESULTS
Smart Bus Lane Usage for Emergency Vehicles

- **Scenario**
  - Pasubio

- **Application Flows**

- **Results (average)**

Source: D. Krajzewicz, L. Bieker, DLR, iTETRIS 2011
Optimized Speed Advisory Application

- **Scenario**
  - Pasubio

- **Application Flows**

- **Results (average)**

<table>
<thead>
<tr>
<th>Speed Limits (Km/h)</th>
<th>50</th>
<th>50</th>
<th>50</th>
<th>70</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>none</td>
<td>500</td>
<td>1000</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>CO2 reduction</td>
<td>0%</td>
<td>13.67%</td>
<td>24.84%</td>
<td>22.21%</td>
<td>28.31%</td>
</tr>
</tbody>
</table>

Source: R. Blokoel, Peek Traffic, iTETRIS 2011
Join the iTETRIS Community!!

www.ict-itetris.eu/10-10-10-community
OPENAIR INTERFACE
EMULATOR
Building Blocks

- Linux IP network interface
- Real L1/L2/L3 protocol stack (not modeled)
- PHY Abstraction
  - Modem, physical channels, along with propagation
- Emu transport mechanism (or combination)
  - Direct memory transfer for realtime behavior with virtualized protocol stack
  - Ethernet (ip multicast) not realtime
    - ECOS and RTNET support realtime Ethernet
- A set of tools
  - Mobility, traffic, channel models
Architectural Design

- **Scalability of the experiment**
  - Protocol virtualization and parallelism
  - Optimized emulated data transport
  - Offloading capabilities depending on Hardware

- **Applicability of the experiment**
  - Real protocol stack (not modeled) interconnected with Linux TCP/IP network stack
  - Hard realtime and soft realtime operations (RTAI)
  - Attach real applications (emulate the remaining traffic)
  - Feed real channel traces
  - Interconnection with a live network
Experiment Design

Web Portal / Interface

Scenario Descriptor → Dispatcher → Result Gen

Console

OAISIM - OAIEMU

XML format

External Application

External Traffic Gen

L3 Protocols

OAI Network Interface

L2 Protocols

PHY Procedures

PHY Abstraction

Emulation Medium

Config Gen

Log Gen

Pkt Tracer

Channel Realization

NB2UE

UE2ENB

Path Loss

Channel Model

Mobility Gen

Channel Descriptor

Traffic Gen

Channel Trace

EMOS

Web Portal / Interface

External Application

External Traffic Gen

L3 Protocols

OAI Network Interface

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Channel Trace

EMOS

OAISIM - OAIEMU

XML format
Emulated data are exchanged through two techniques

- Shared memory
- IP multicast over Ethernet (or any other medium)
Use case: Smart City (LOLA Testbed)

- City/hot zone in the area of 2000x2000
- 4 static dense small cells in grid of 2x2 (pico cell) and 60 UEs randomly distributed with mixed mobility
- Mixed human and machine traffics based on WP3 models

![Diagram of network with eNBs and UEs connected through Ethernet Switch and WANEM to Application Server.]

Physical machine

WANEM
e.g. 2ms delay
1Mb/s bandwidth

Application Server
## OPENAIR INTERFACE

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<tr>
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<th>Reproducibility</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation</td>
<td>Soft Realtime Emulation</td>
<td>Hard Realtime Emulation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Abstraction Level</th>
<th>Realism Level</th>
</tr>
</thead>
</table>

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- p 35
Test Bed Building Blocks

- **Experimental Licenses from ARCEP (French Regulator) for medium-power outdoor network deployments**
  - 1.9 GHz TDD, 5 MHz channel bandwidth
  - 2.6 GHz FDD (two channels), 20 MHz channel bandwidth
  - 800 MHz FDD (two channels): 10 MHz channel bandwidth

- **IDROMEL reconfigurable radio architectures**
  - Agile RF and ExpressMIMO fully reconfigurable RF and baseband DSP
  - Heterogeneity in networking protocols
  - Full SDR description of air interfaces

- **Air interface applications**
  - LTE / LTE-A
  - DAB
  - IEEE 802.11p PHY

- **Real-time Two-way and Multiuser Channel sounding**

GNU GPL License
Summary - Thank you for your Attention!!

- Each Methodology is adapted to specific requirements

Join the Communities:
- iTETRIS: www.ict-itetris.eu/10-10-10-community
- OpenAir Interface: www.openairinterface.org
- OpenAir Interface EMU: emu.openairinterface.org
- More Information: its@eurecom.fr

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