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In collaboration with:
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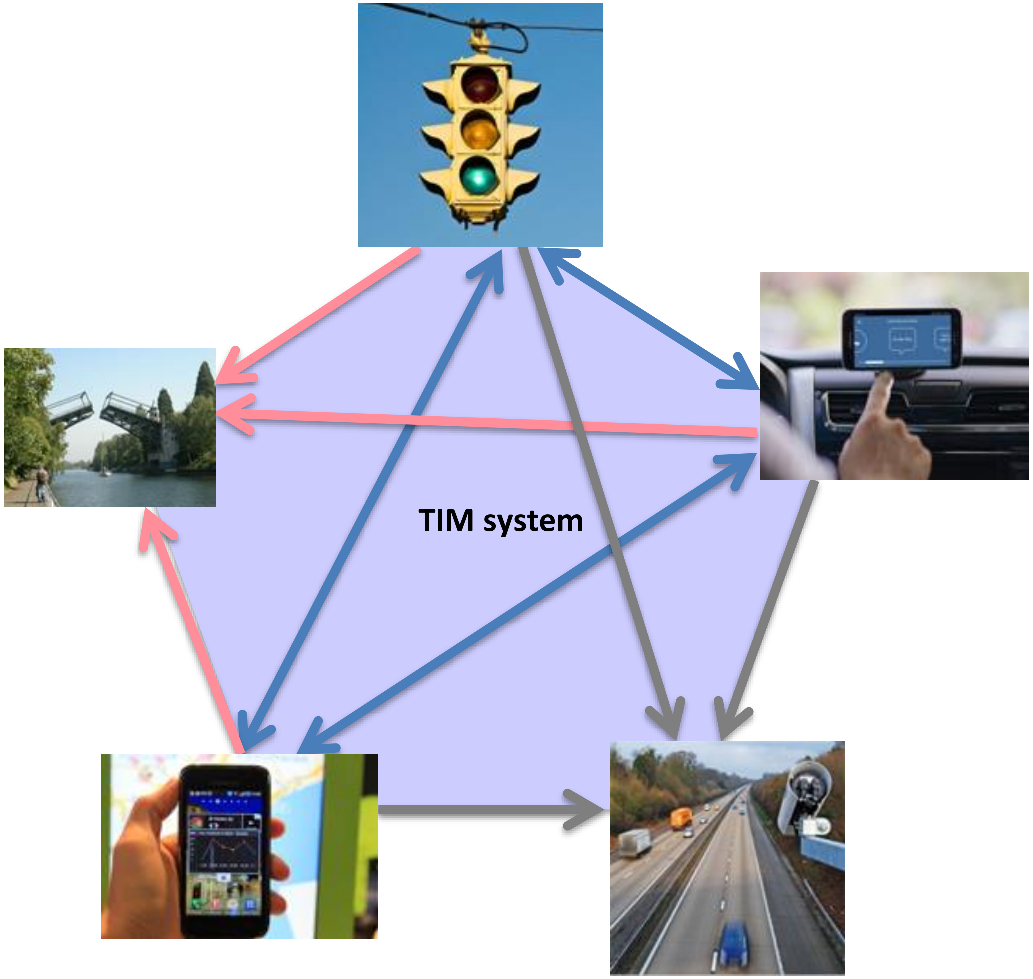
Enabling Emergent Mobile Systems in the IoT: functional and QoS interoperability at the middleware layer

Emergent mobile systems in the IoT

- Traffic Information Management (TIM) system:

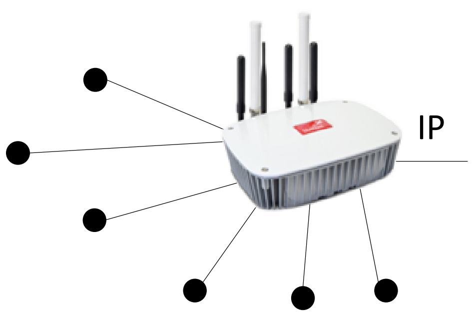
Heterogeneous

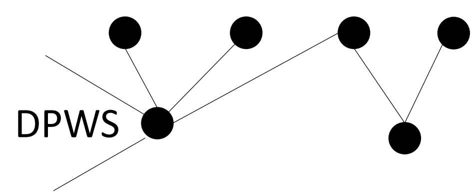


Dynamic

IoT heterogeneity at multiple layers

Application layer	⟺	Application layer
Middleware layer	⟺	Middleware layer
Transport Layer		Transport Layer
Network layer		Network layer
Data Link layer (MAC & LLC)	⟺	Data Link layer (MAC & LLC)
Physical layer	⟺	Physical layer





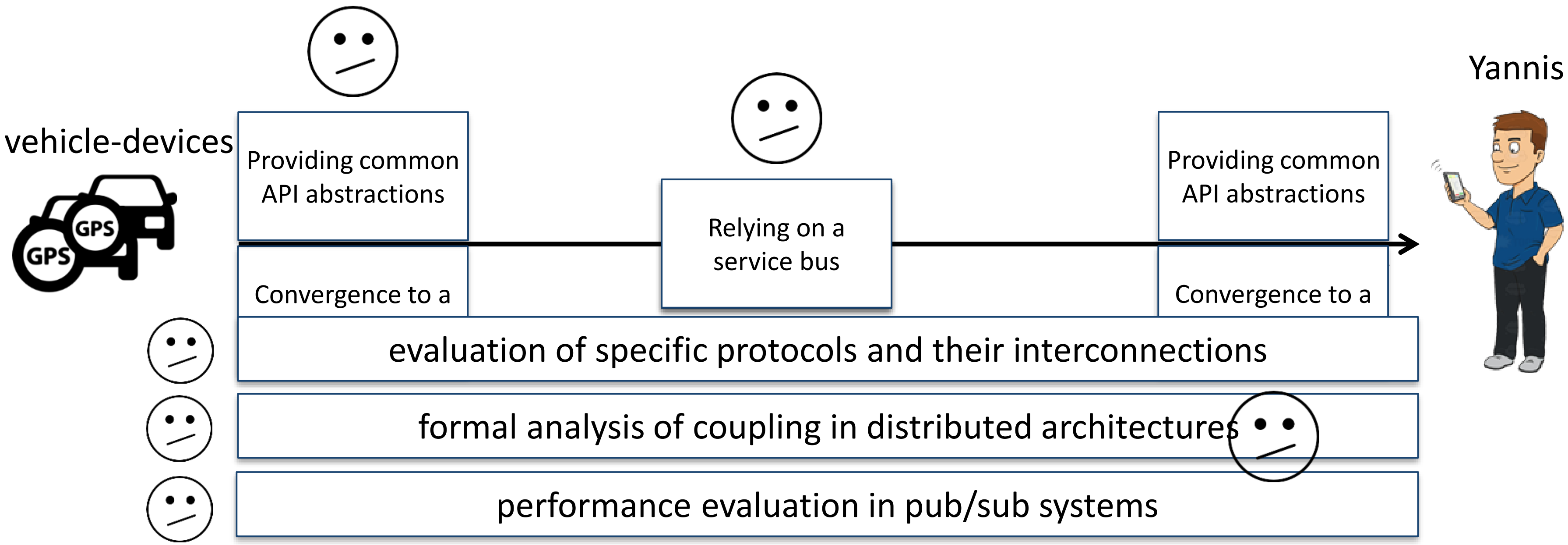
Middleware protocols in the mobile IoT

DPWS CoAP MQTT ZeroMQ WebSockets ....

Client-server Pub/sub Streaming ....

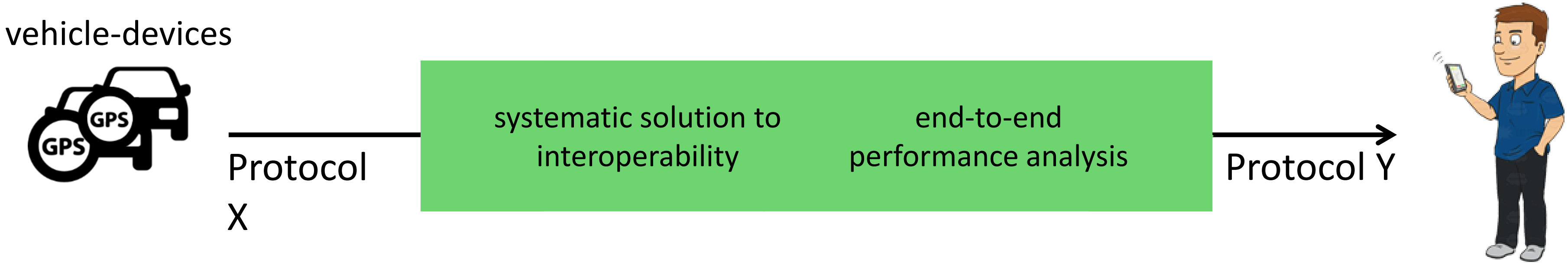
reliable/unreliable mobile connectivity ....

Heterogeneous interconnections in the mobile IoT



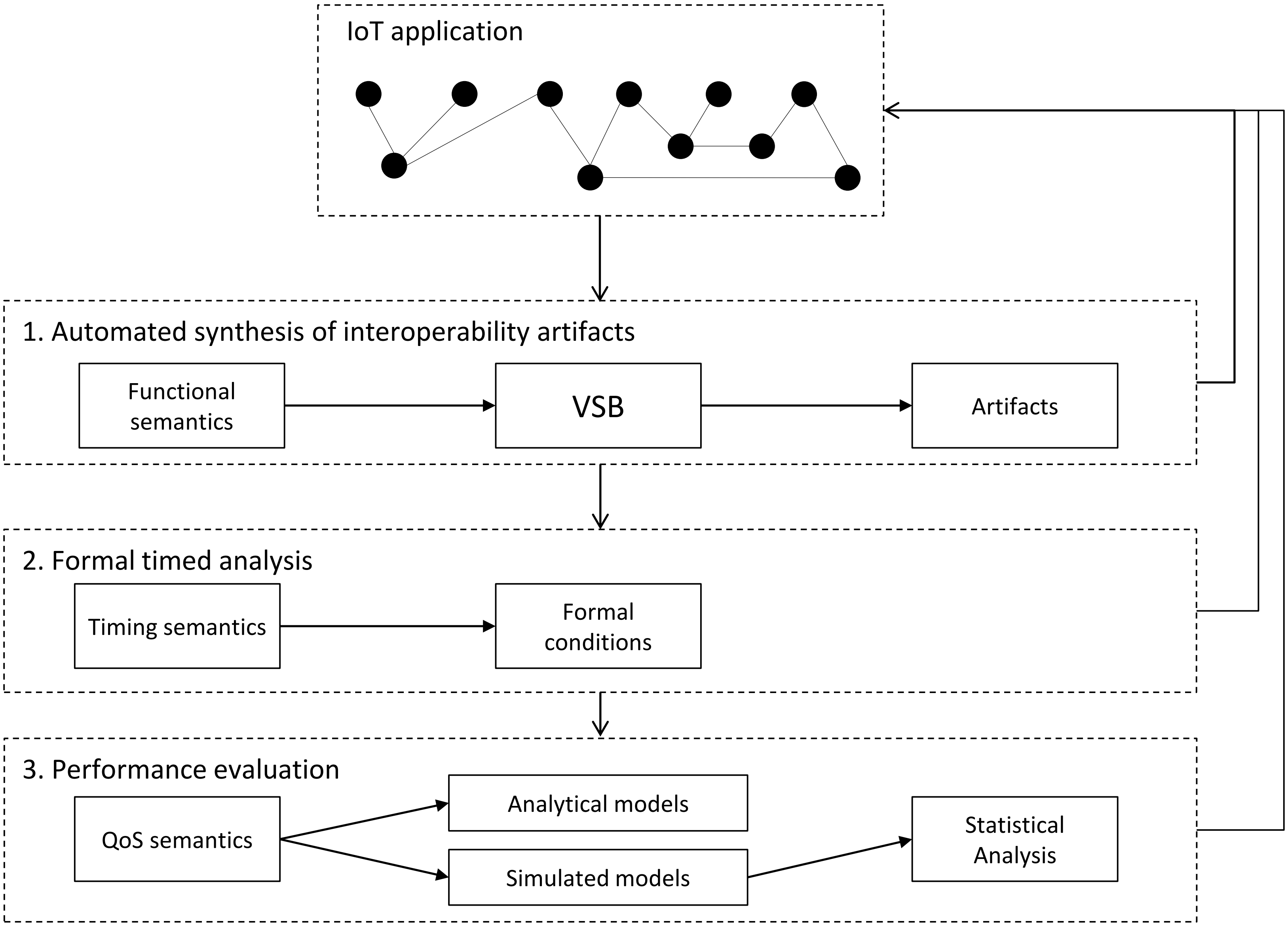
- How to enable interconnections in the mobile IoT ?
- What is the end-to-end QoS of the interconnection ?

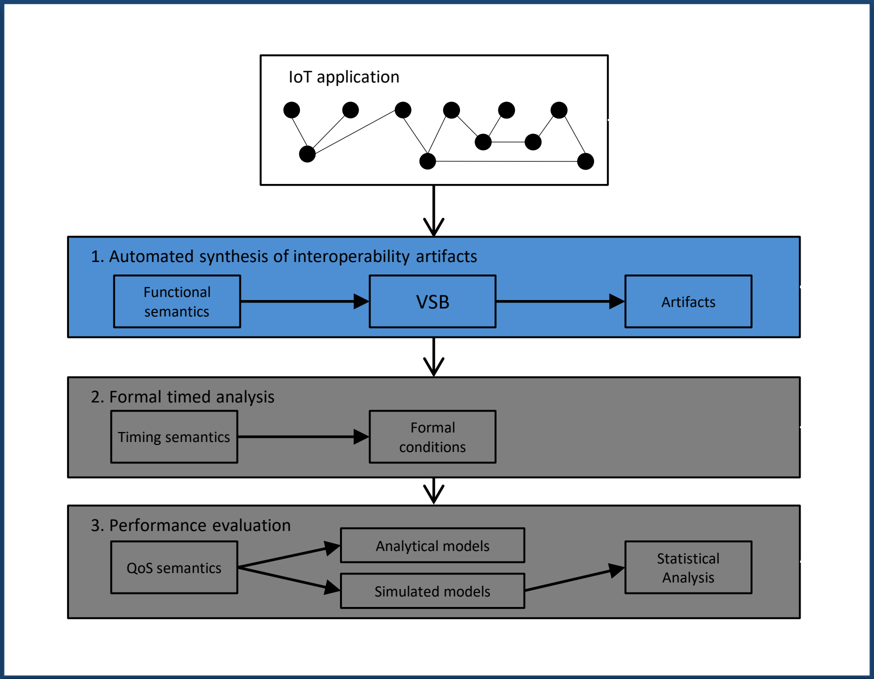
Our solution



"Enabling heterogeneous interactions in the mobile IoT calls for automated synthesis of interoperability *artifacts* as well as evaluation of the interoperability effectiveness in terms of end-to-end QoS"

Platform for functional and QoS interoperability

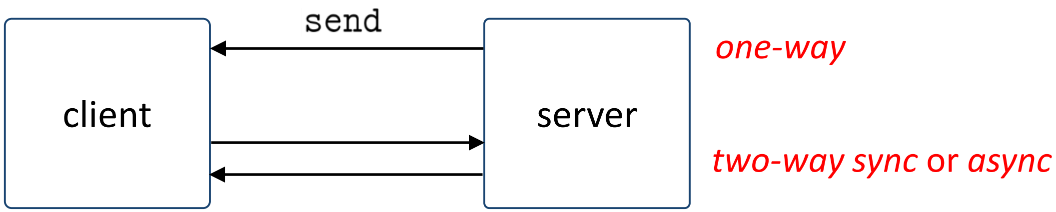




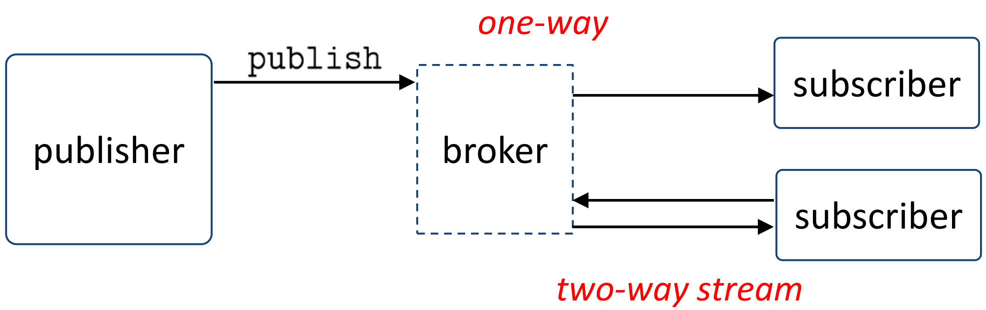
1

Automated synthesis of interoperability artifacts

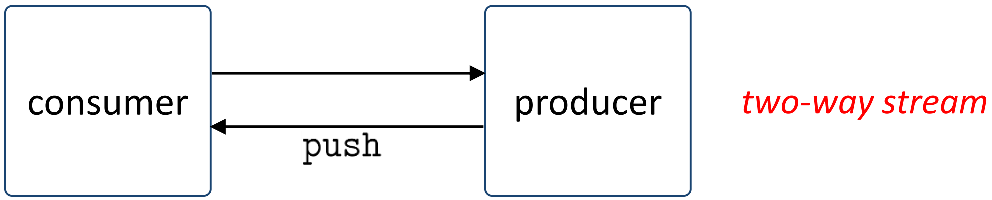
Models for core communication styles



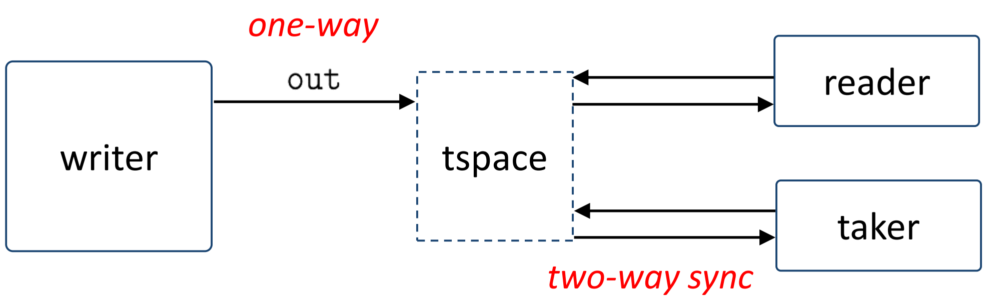
Client–Service (CS)
- Tight Time & Space Coupling



Publish-Subscribe (PS)
- Time & Space Decoupling



Data Streaming (DS)
- Tight Time & Space Coupling



Tuple Space (TS)
- Time & Space Decoupling

Generic Middleware (GM) connector model

- Our generic connector defines 4 basic interaction types:

one-way
two-way async
two-way sync
two-way stream

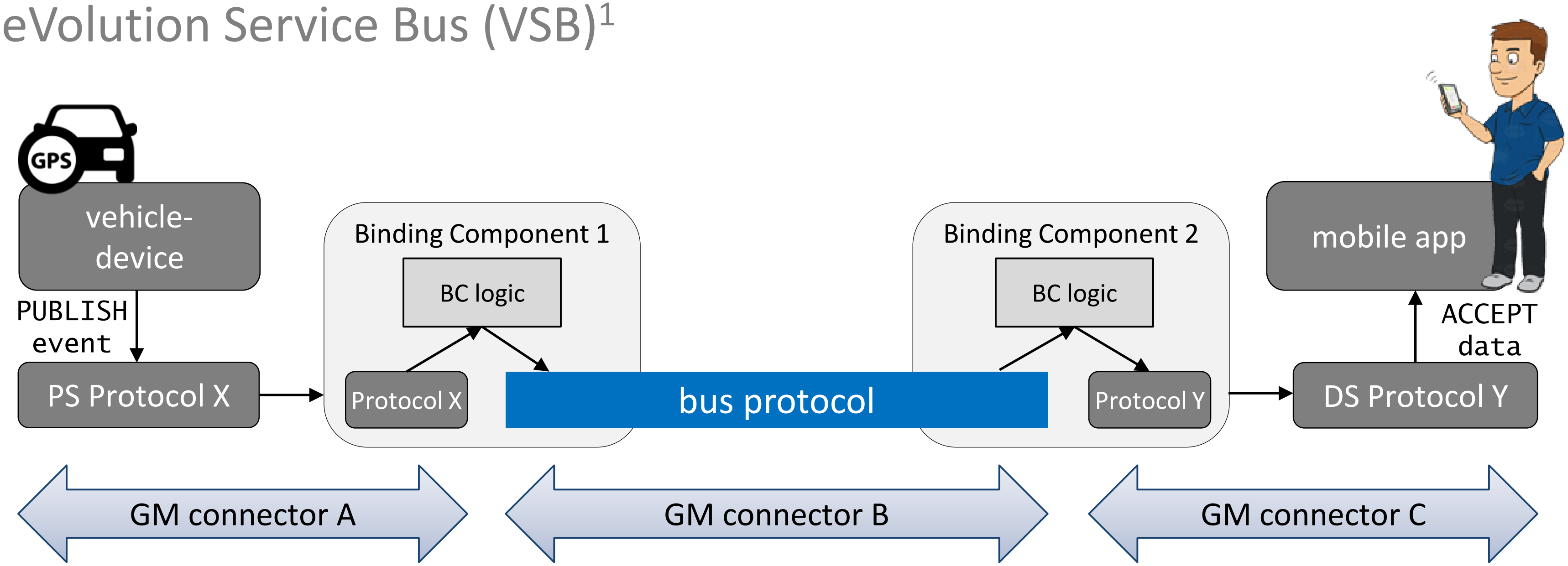
each interaction is represented as combination of **post** and **get** primitives

post and **get** primitives abstract CS, PS, DS and TS primitives

We rely on the GM abstraction to introduce our middleware protocol interoperability solution

Our middleware protocol interoperability solution

➢ eVolution Service Bus (VSB)[1]

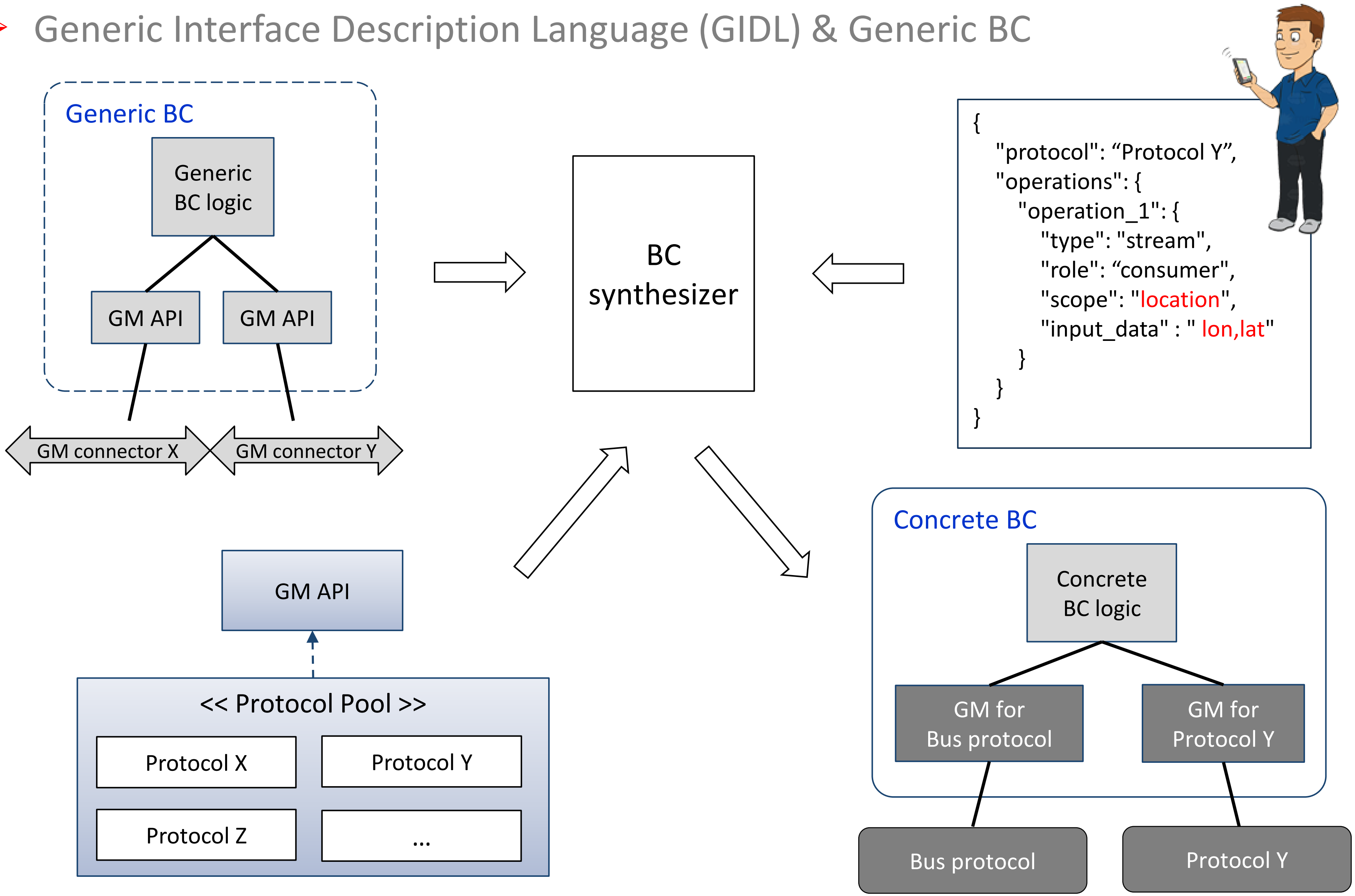


- BC architecture: relies on GM for automated BC synthesis
- Primitives & data conversion between the bus protocol and the Things' protocols
- A universal way to describe the Things' I/O required

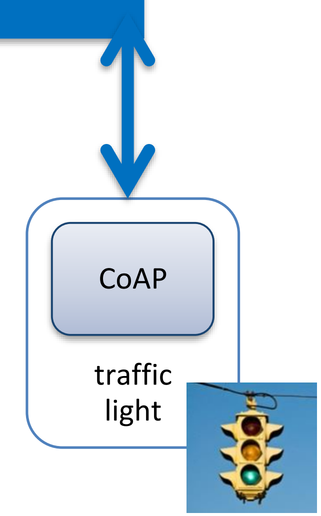
[1] G. Bouloukakis et al., ICSOC, 2016

Automated BC synthesis

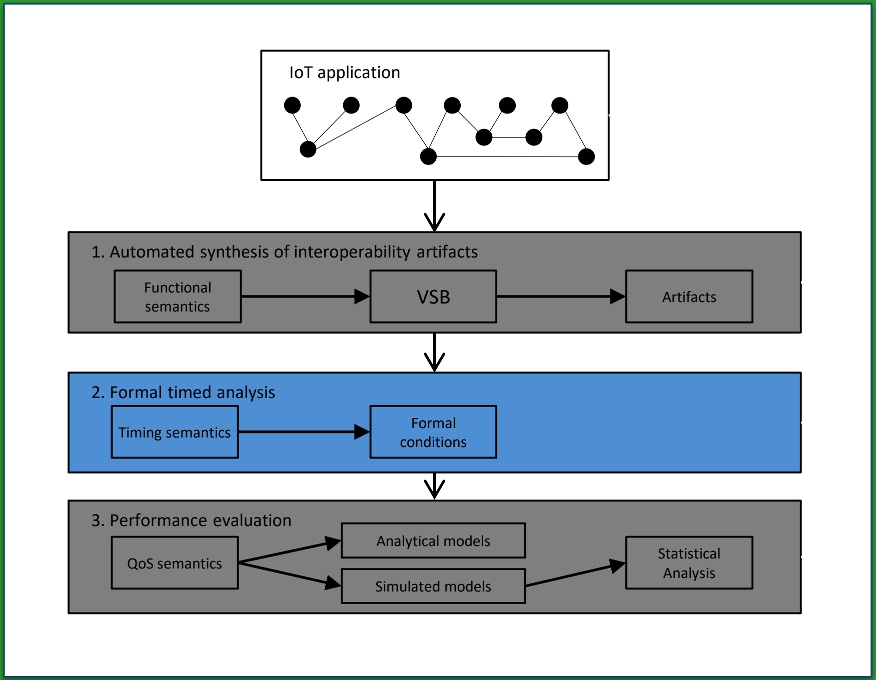
➢ Generic Interface Description Language (GIDL) & Generic BC



VSB novelty



- Lightweight bus
- Any bus protocol
- BCs employed only when necessary
- Support for any protocol classified under CS, PS, DS & TS
- Automated BC synthesis
- 75-96 % person-hours reduction when using VSB
- Evolution support
- QoS awareness

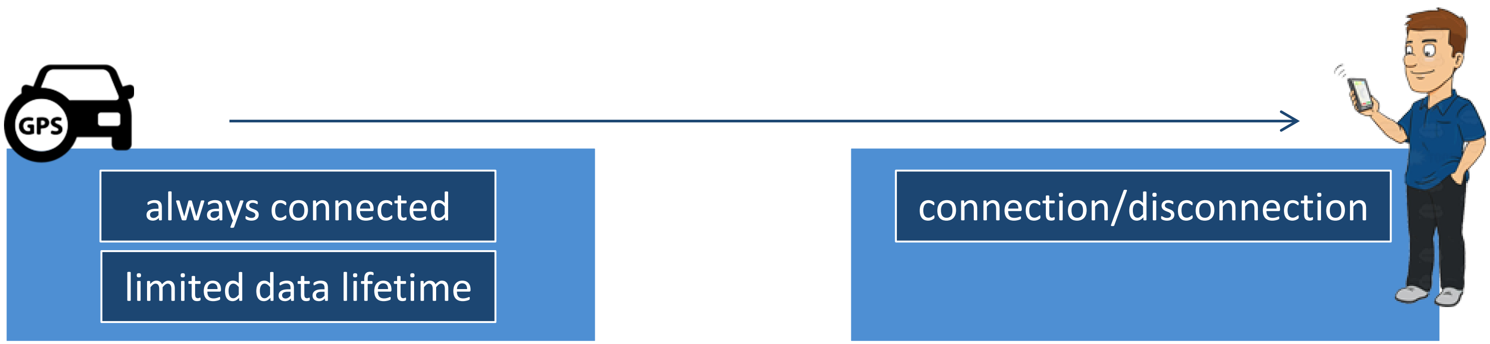


2
Formal timed analysis

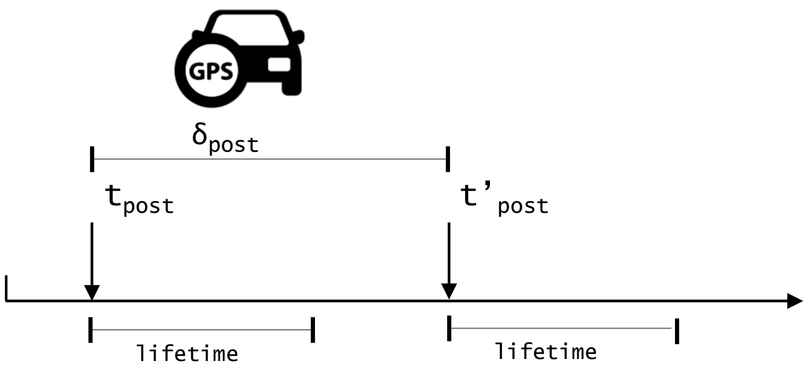
Timing model for IoT interactions

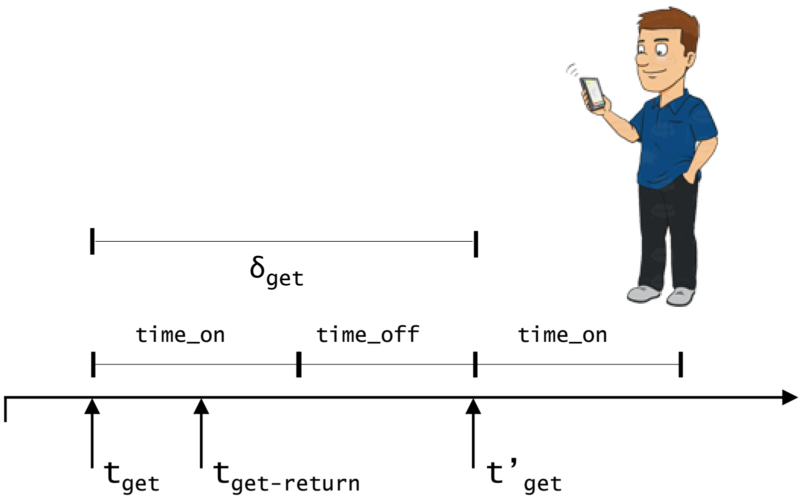
➢ We introduce a unifying timing model for IoT interactions by relying on GM.

❑ GM one-way timing model:

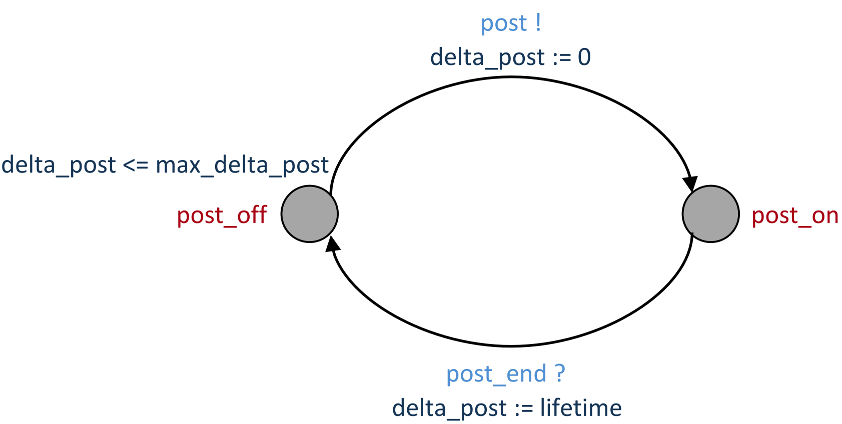


GM one-way timing analysis

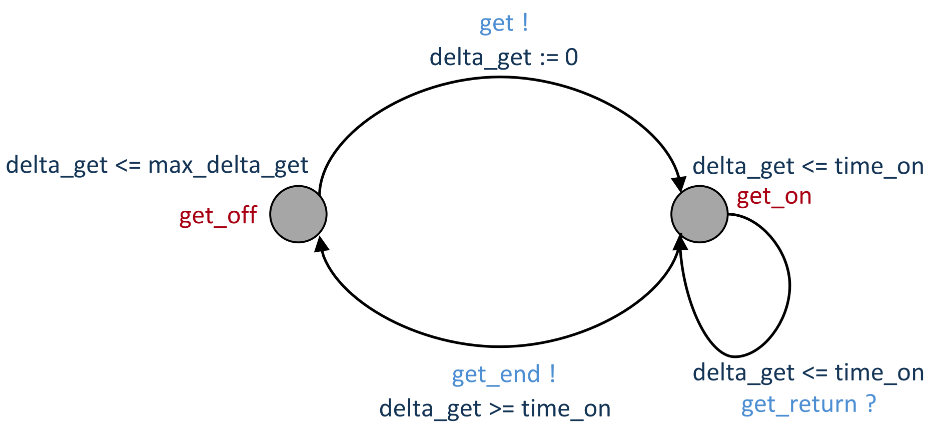




GM sender automaton

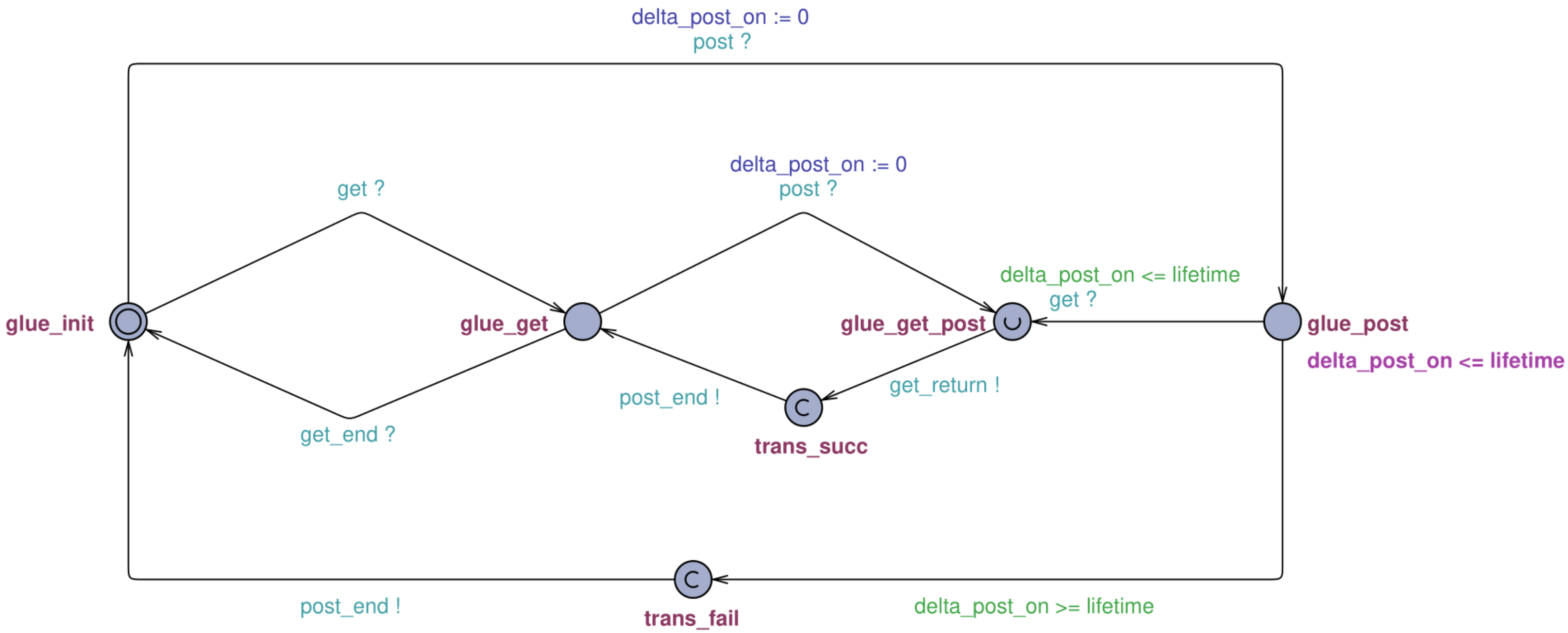


GM receiver automaton



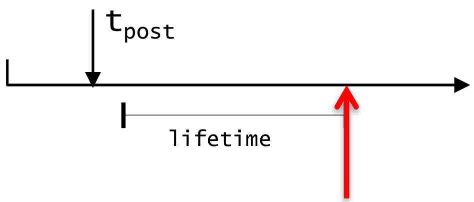
Glue automaton & Verification

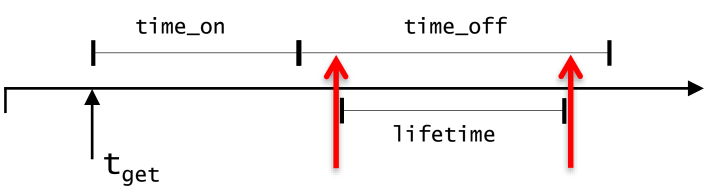
- Sender and Receiver automata interact via the Glue automaton

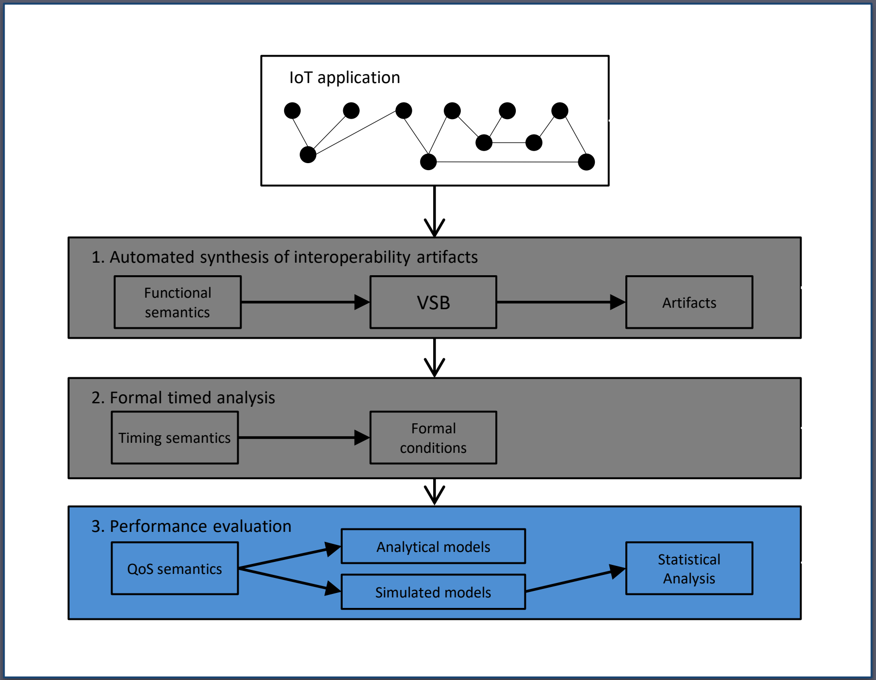


- Safety (A[] ϕ) property verified using UPPAAL – necessary condition for failed interactions :

```
A[] glue.trans_fail imply (sender.post_on and receiver.get_off and
delta_post==lifetime and delta_get - time_on>=lifetime)
```



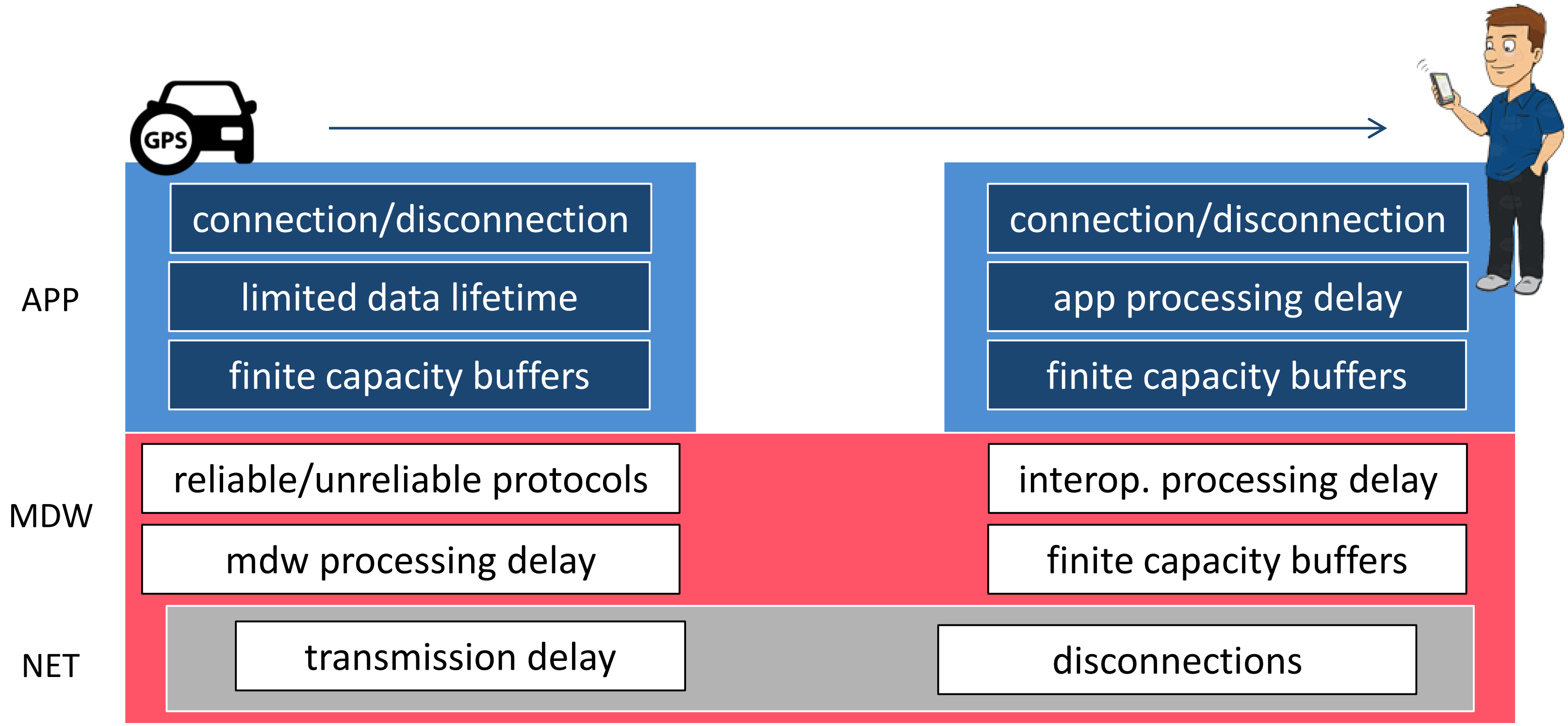




3
Performance evaluation

IoT Interactions across Multiple Layers

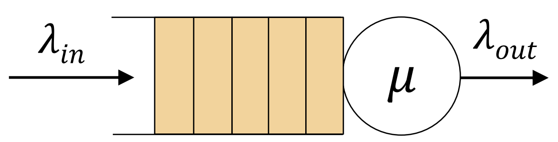
- We enrich our timing model with more realistic constraints found across multiple layers in the IoT



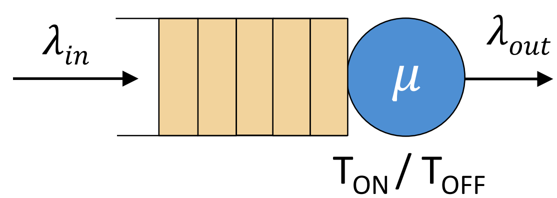
Base queueing models for mobile IoT interactions

- We model the end-to-end path of an IoT interaction by using a combination of different types of queueing models

continuous queue

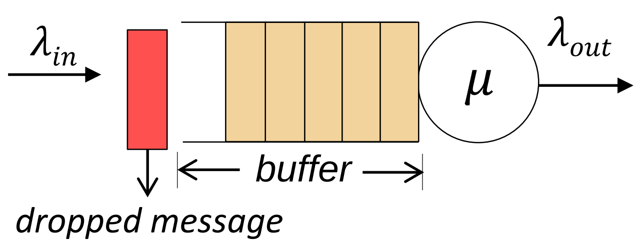


intermittent (ON/OFF) queue[1,2]

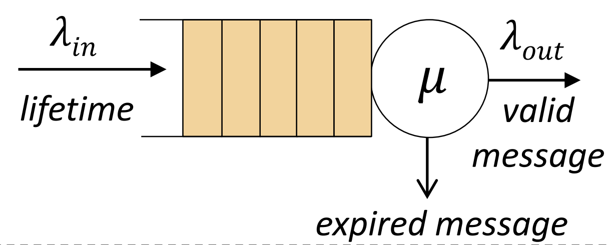


- Additional features:

finite capacity queue



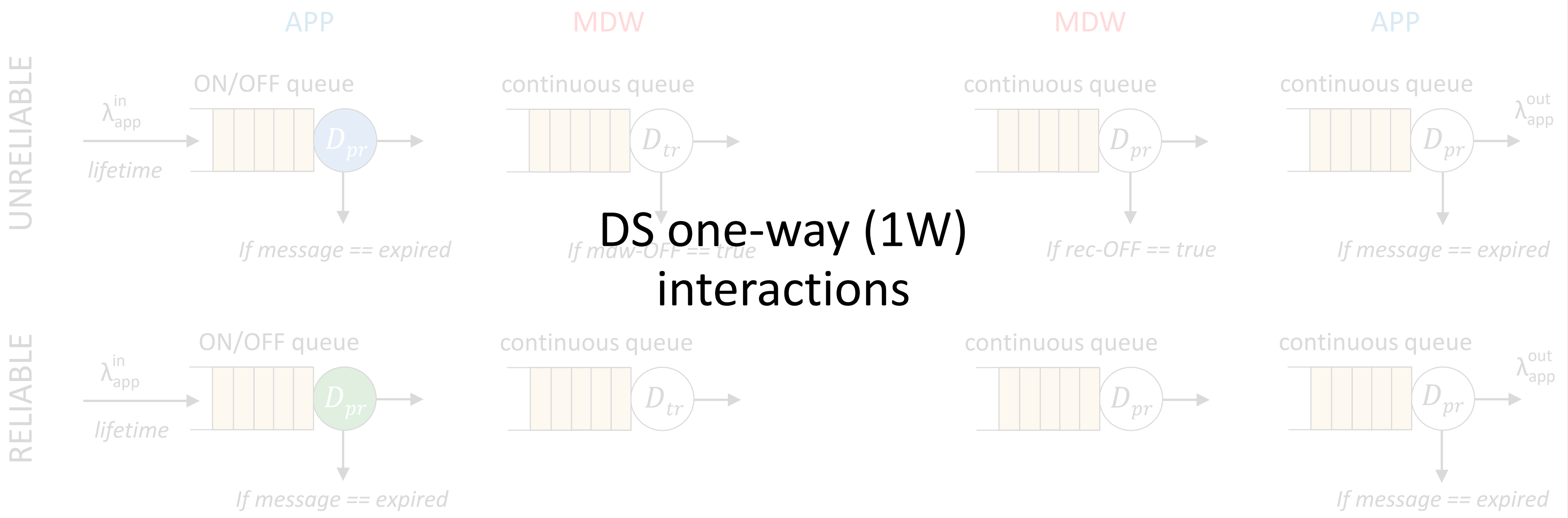
messages exp. queue



[1] G. Bouloukakis et al., ICC, 2017
[2] G. Bouloukakis et al., ICPE, 2017

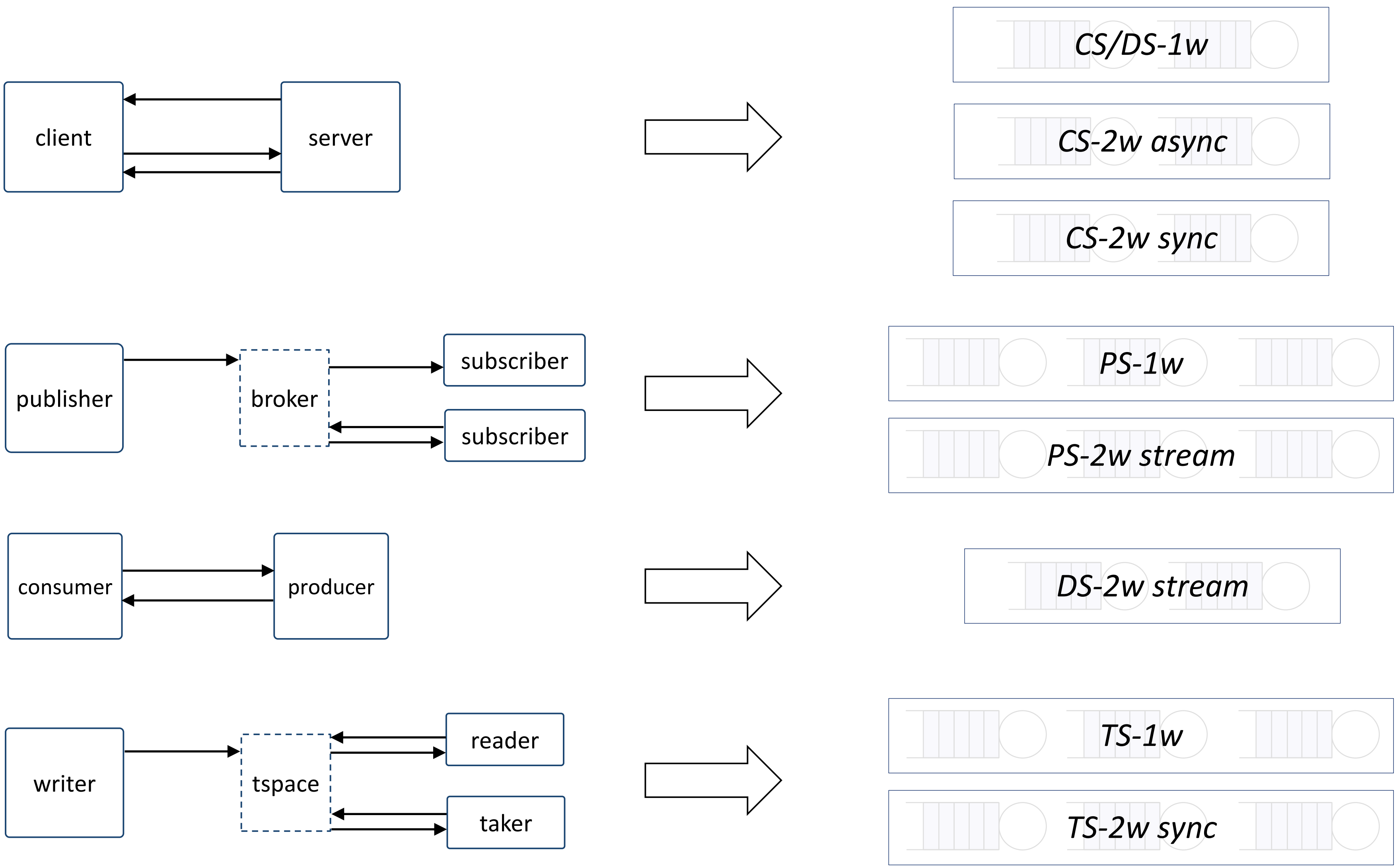
DS QoS model for mobile IoT interactions

- We model **reliable** or **unreliable** interactions by using our queueing models



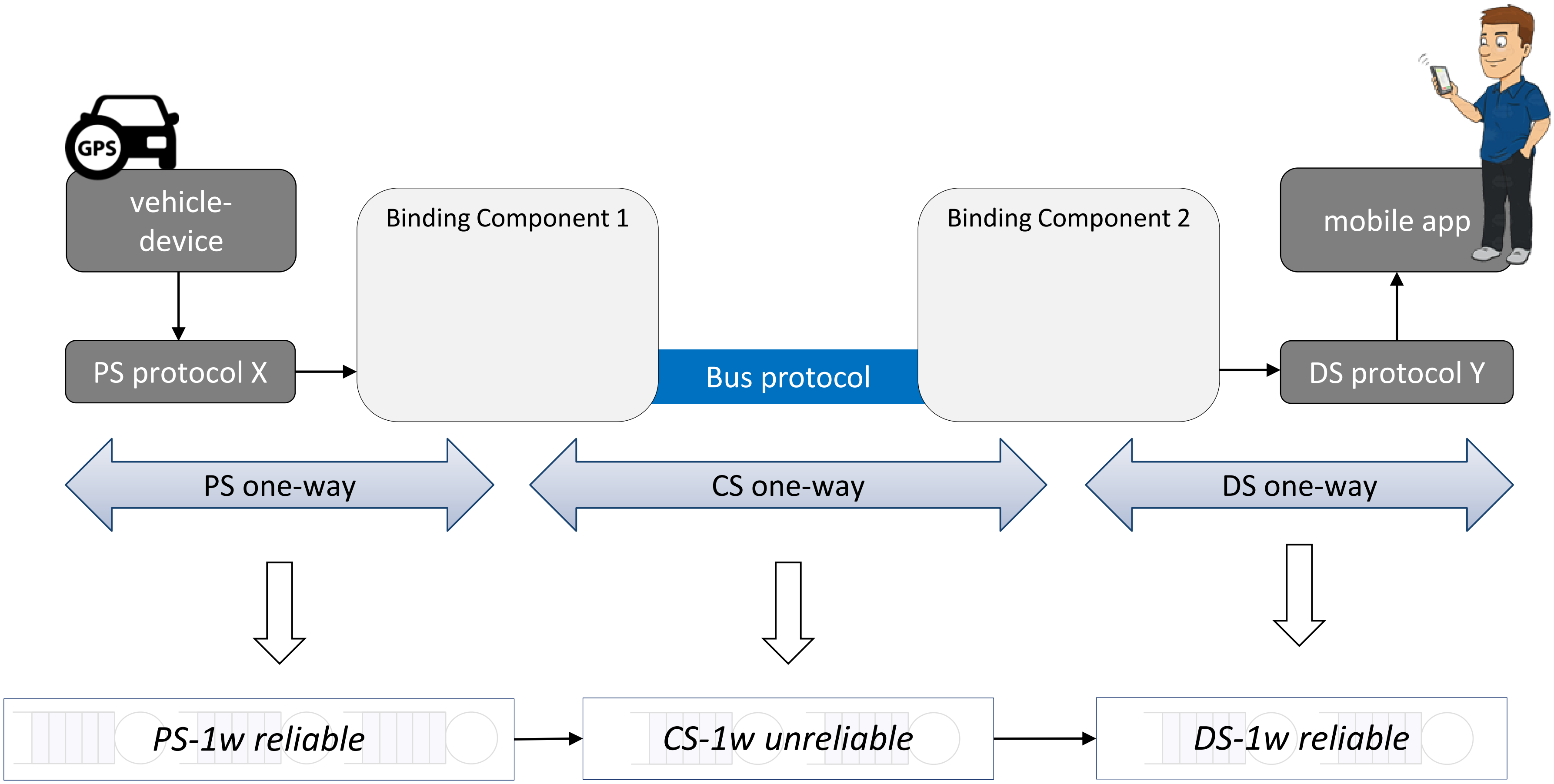
DS one-way (1W) interactions

Performance modeling patterns



What about heterogeneous interactions?

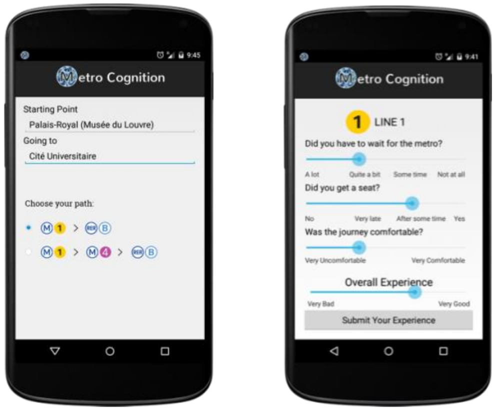
One-way PS to DS interconnection



Evaluation Results

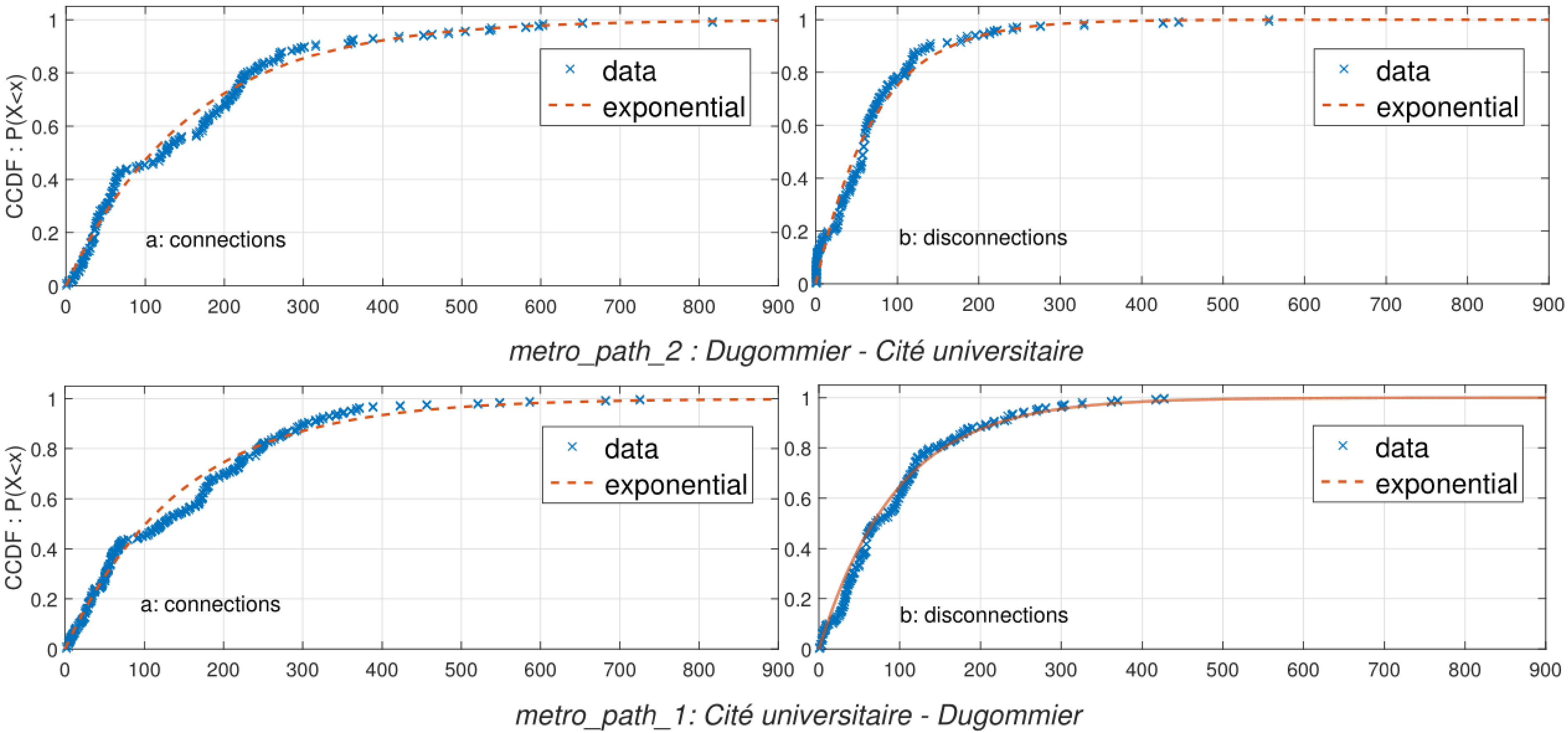
1. ON/OFF queueing model validation
2. One-way PS to DS end-to-end performance evaluation

- We validate the ON/OFF QM validation through:
  - probability distributions
  - arrival rates extracted from the Orange CDR dataset over Senegal[1]
  - **ON/OFF connectivity traces collected in the metro of Paris[2]**



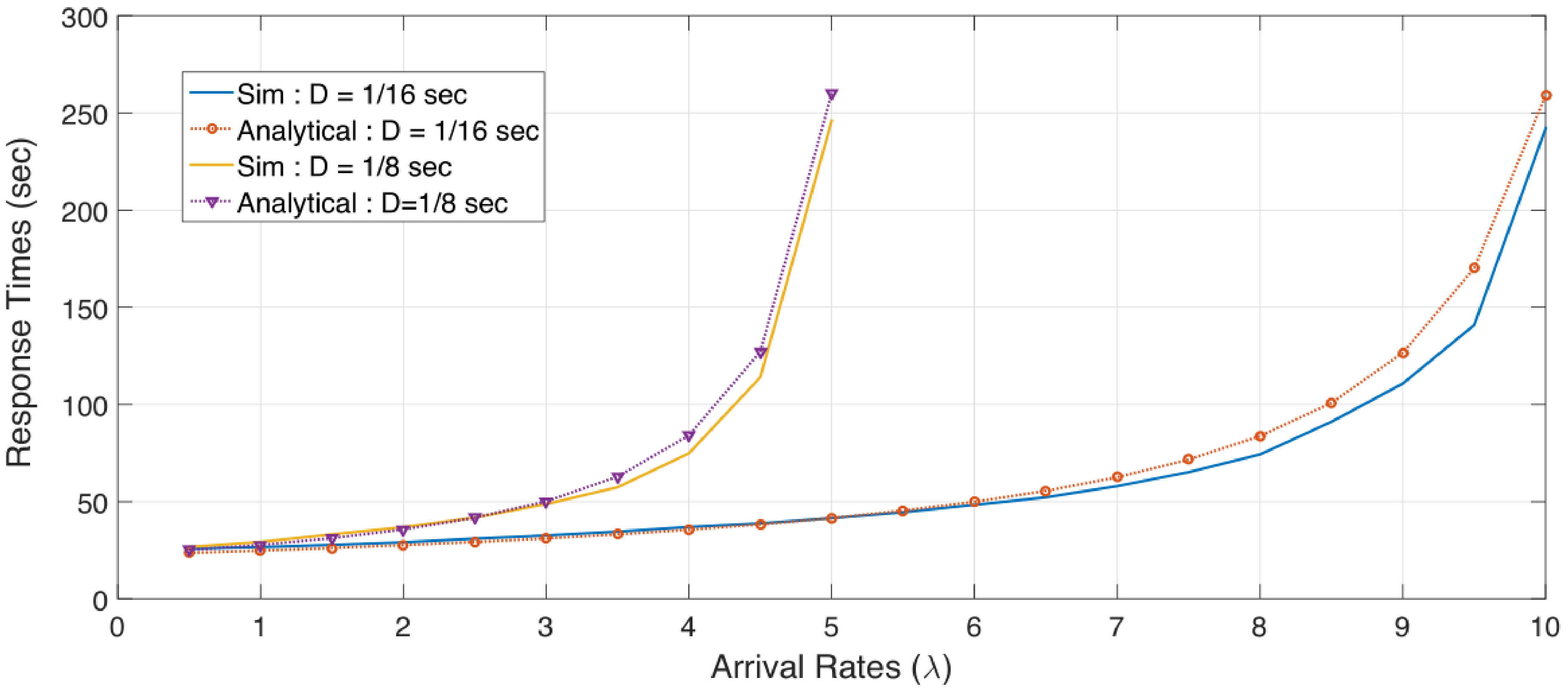
[1] G. Bouloukakis et al., WiMob, 2015
[2] G. Bouloukakis et al., ICPE, 2017

ON/OFF QM Validation using Connectivity traces (1)



1. *Cité Universitaire → Dugommier*; journeys : 34; total duration : 15.18 hours; average duration journey : 26.8 min; T_{ON} = 2.43 min and T_{OFF} = 1.6 min.
2. *Dugommier → Cité Universitaire*; journeys : 28; total duration : 12.13 hours; average duration journey : 26 min; T_{ON} = 2.5 min and T_{OFF} = 1.2 min.

ON/OFF QM Validation using Connectivity traces (2)



- 2nd path: *Dugommier → Cité Universitaire*
- For high rates, there is a quite good match with maximum difference of about 10%.

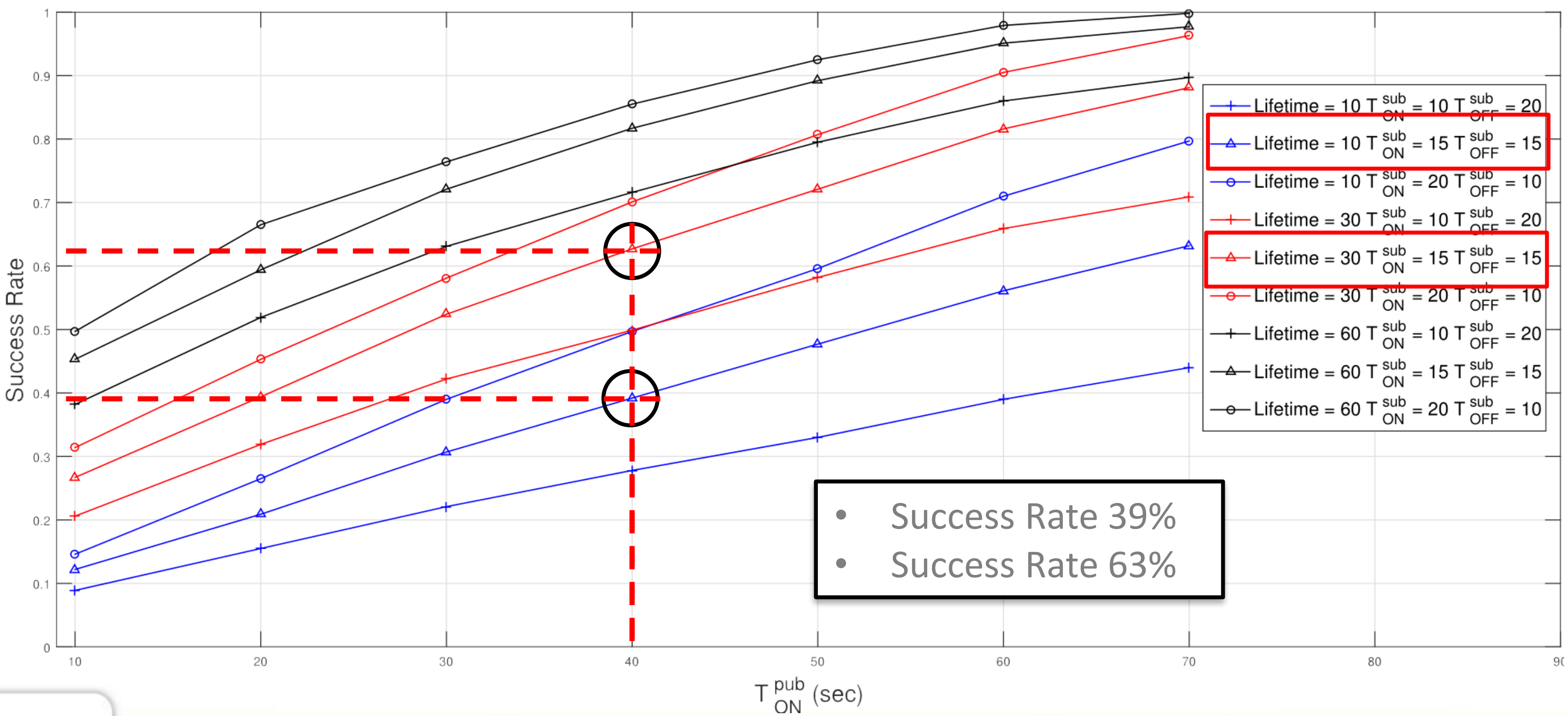
PS to DS performance evaluation: success rates

$T_{ON}^{pub} + T_{OFF}^{pub} = 80$ sec

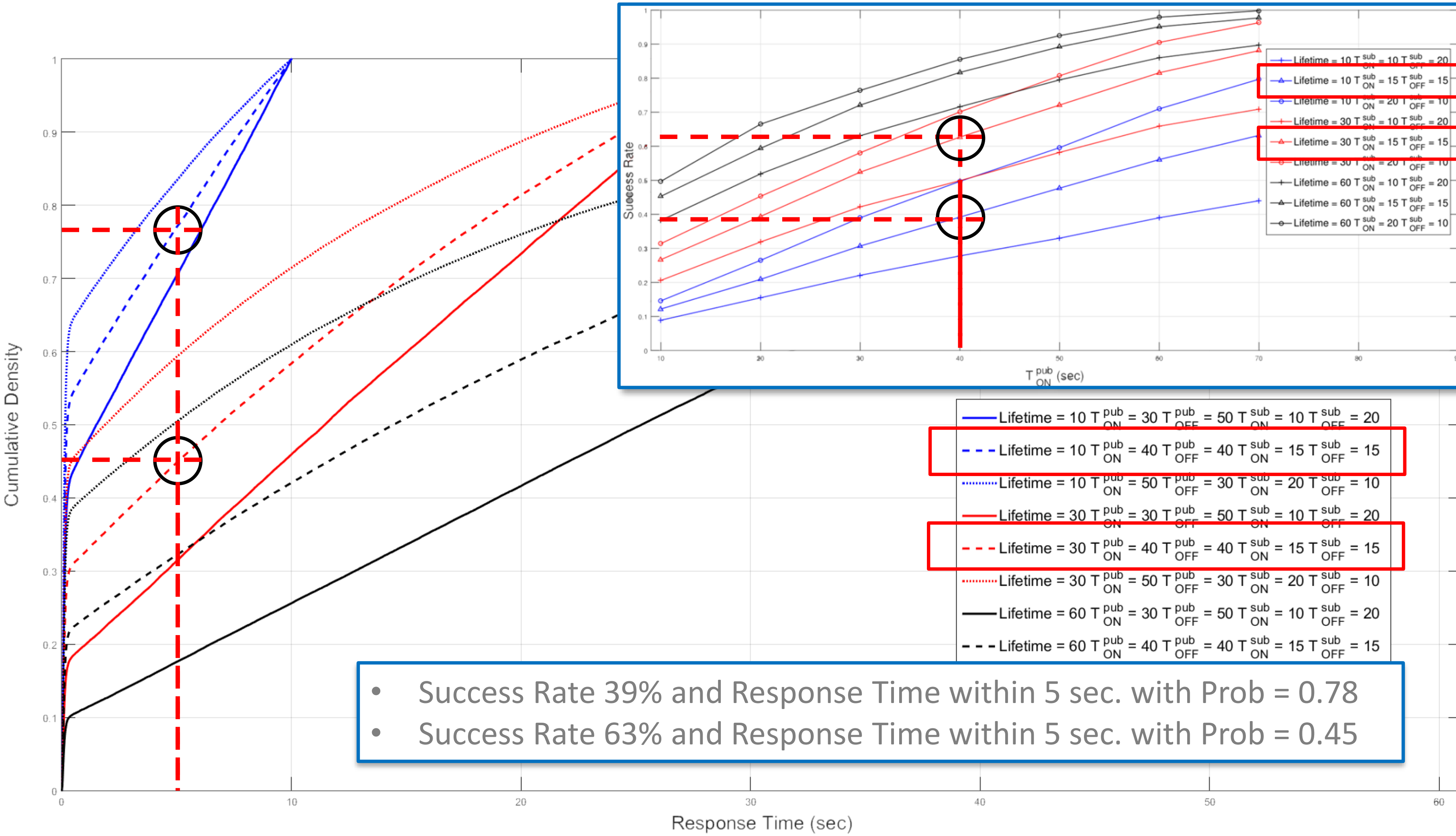
$\lambda_{app}^{in} = 2$ msg/sec

lifetime = 10, 20 and 30 sec

$T_{ON}^{sub} + T_{OFF}^{sub} = 30$ sec



PS to DS performance evaluation: response times



- Success Rate 39% and Response Time within 5 sec. with Prob = 0.78
- Success Rate 63% and Response Time within 5 sec. with Prob = 0.45

➢ Lower lifetime periods produce improved response time (but with lower success rates)

4
Conclusions & future work

Conclusions

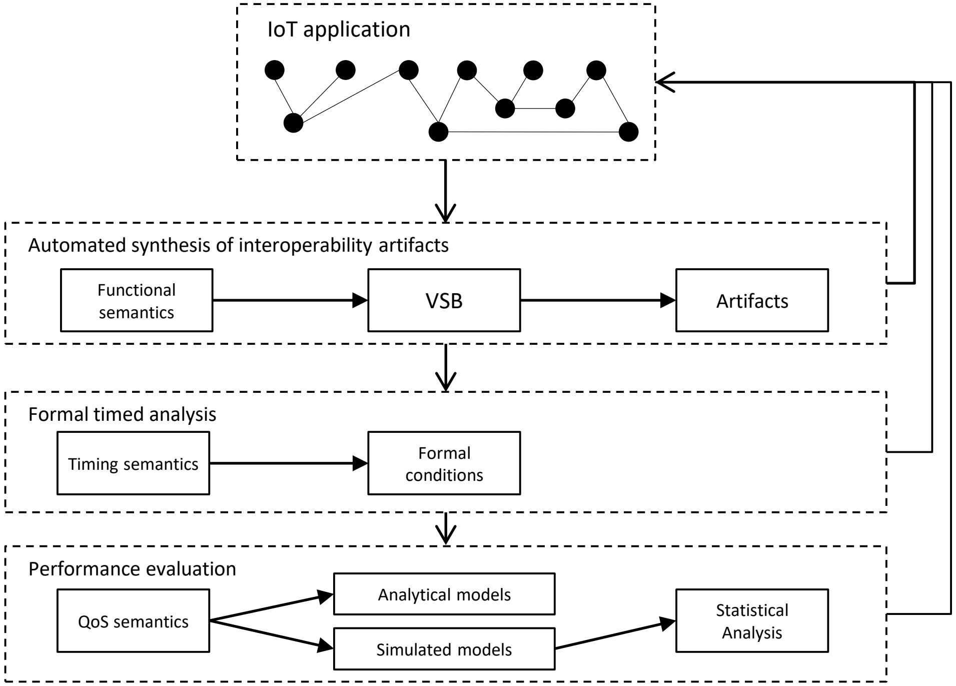
➢ We introduce a platform that enables functional interoperability and QoS-related interoperability evaluation with focus on the mobile IoT

We enable system designers to:

1. Automatically map functional semantics of heterogeneous Things for integrating them into IoT applications

2. Formally analyze time semantics of heterogeneous IoT interactions for ensuring high success rates

3. Analyze realistic QoS semantics of heterogeneous IoT interactions for assessing end-to-end performance



➢ Our platform provides precise design-time modeling, analysis and software synthesis to ensure accurate runtime system behavior.

Future Work

- From design for interoperability and design-time evaluation to runtime adaptation:
  1. Dynamic composition of heterogeneous Things in emergency scenarios:
     - face possible emergencies and ensure safety through the composition of Things
  2. QoS-aware adaptation of IoT middleware protocols
     - detect performance degradation at runtime and decide appropriate actions
  3. Ensure cross-layer resilience for heterogeneous IoT interactions
     - control the underlying IoT networking capabilities to improve and adapt IoT interactions
  4. Explore large-scale IoT deployments
     - explore the deployment of our interoperability, resilience and adaptation solutions in large-scale IoT applications

Software artifacts and adoption

- VSB is used as a core component in H2020 CHOReVOLUTION project
- Download VSB:
  - https://repository.ow2.org/nexus/content/repositories/releases
- Download Eclipse plugin for defining Things' GIDLs:
  - http://nexus.disim.univaq.it/content/sites/chorevolution-modeling-notations
- VSB development and runtime demo:
  - https://youtu.be/UgfM3810RS8
- Download MobileJINQS:
  - http://xsb.inria.fr/MobileJINQS.jar
- MetroCognition mobile app:
  - https://play.google.com/apps/testing/edu.sarathi.metroCognition

Publications (1/2)

- G. Bouloukakis, I. Moscholios, N. Georgantas, V. Issarny, "Performance Modeling of the Middleware Overlay Infrastructure of Mobile Things", ICC, May 2017, Paris, France
- G. Bouloukakis, N. Georgantas, A. Kattepur, V. Issarny, "Timeliness Evaluation of Intermittent Mobile Connectivity over Pub/Sub Systems", ICPE, April 2017, L'Aquila, Italy
- G. Bouloukakis, N. Georgantas, S. Dutta, V. Issarny, "Integration of Heterogeneous Services and Things into Choreographies", ICSOC, October 2016, Banff, Alberta, Canada
- V. Issarny, G. Bouloukakis, N. Georgantas, B. Billet, "Revisiting Service-oriented Architecture for the IoT: A Middleware Perspective", ICSOC, October 2016, Banff, Alberta, Canada
- G. Bouloukakis, R. Agarwal, N. Georgantas, A. Pathak, and V. Issarny, "Leveraging CDR datasets for Context-Rich Performance Modeling of Large-Scale Mobile Pub/Sub Systems", WiMob, October 2015, Abu Dhabi, UAE

Publications (2/2)

- G. Bouloukakis, R. Agarwal, N. Georgantas, A. Pathak, and V. Issarny, "Towards Mobile Social Crowd-Sensing for Transport Information Management", NetMob - MIT Media Lab, April 2015, Boston, United States
- G. Bajaj, G. Bouloukakis, A. Pathak, S. Pushpendra, N. Georgantas, and V. Issarny, "Toward Enabling Convenient Urban Transit through Mobile Crowdsensing", ITSC, September 2015, Gran Canaria, Spain
- A. Kattepur, N. Georgantas, G. Bouloukakis, and V. Issarny, "Analysis of Timing Constraints in Heterogeneous Middleware Interactions", ICSOC, November 2015, Goa, India
- N. Georgantas, G. Bouloukakis, S. Beauche, V. Issarny, Service-oriented Distributed Applications in the Future Internet: The Case for Interaction Paradigm Interoperability, ESOCC, September 2013, Malaga, Spain

Thank you!

MiMove Project Team - *https://mimove.inria.fr*