From Power domains to Power Grids

Holger Hermanns

Saarland University

joint work with

Pascal Berrang, Arnd Hartmanns

Challenge

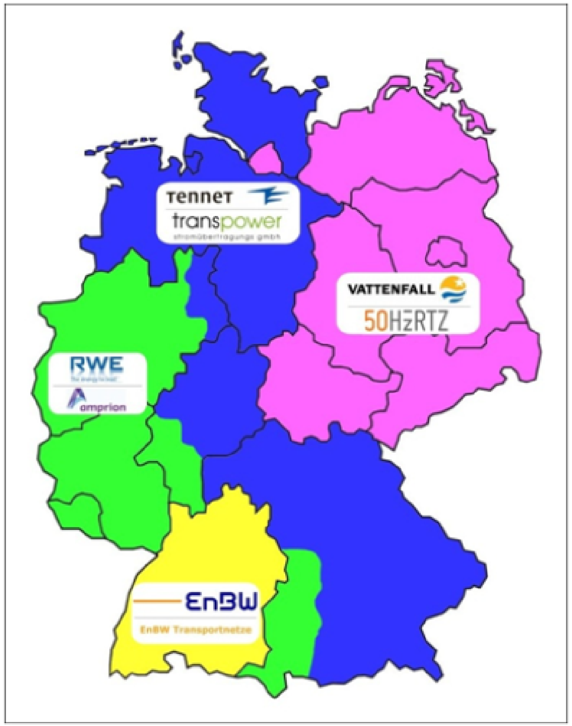
Electrifying Challenge

Germany

- gives priority to
  renewable sources

- rewards renewable energy
  above market price

- drops nuclear energy
  after Fukushima incident

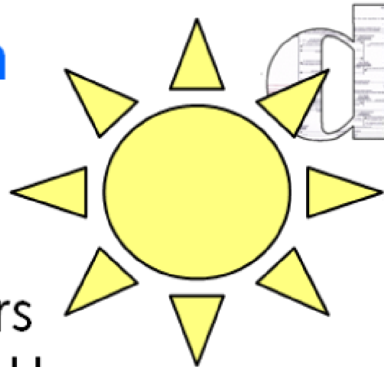


source: http://www.wikipedia.org

More challenges:

Sweden, UK, France, Fiji, …

Power Grids and Microgeneration

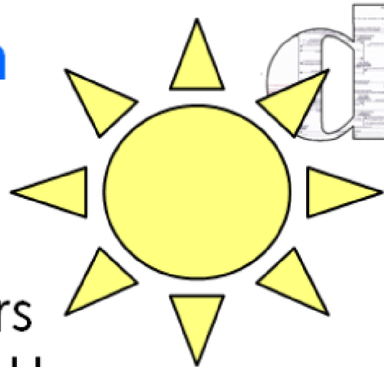


Renewable energies are on the rise
⇨ particularly in Germany
⇨ particularly photovoltaic generators on rooftops of residential houses

2009: 10 GW **2011: 25 GW** **2020: ?? GW**

That is so great!

Power Grids and Microgeneration



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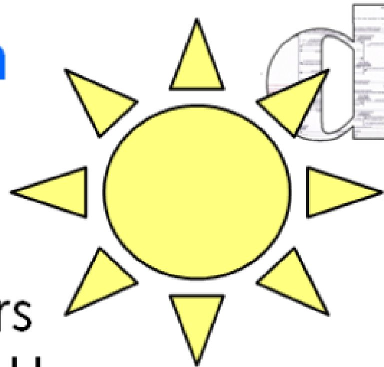
Power Grids and Microgeneration



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That is so great!

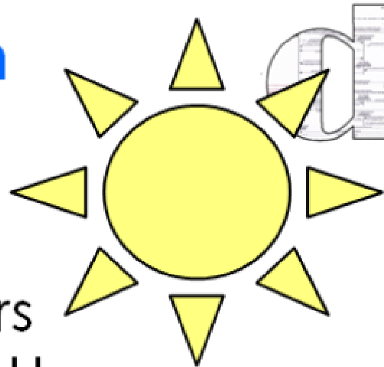
Is it?

>60% renewable on June 16, 2013

German peak load: around 80 GW

European grid:
15 GW ≈ 1 Hz
Target: [49.8, 50.2] Hz

Power Grids and Microgeneration



Renewable energies are on the rise
⇨ particularly in Germany
⇨ particularly photovoltaic generators
on rooftops of residential houses

2009: 10 GW **2011: 25 GW** **2020: ?? GW**

⇨ good control strategies needed
for photovoltaic microgenerators

hundreds of thousands *geographically distributed*

distributed *self-stabilising*

~~centralised~~ *simple*

Current Control Strategies

On-off controller **EN 50438**: enforced in 2007
when `f > 50.2 Hz`
switch off

about 380 thousand on-off controllers on German rooftops now

Linear controller

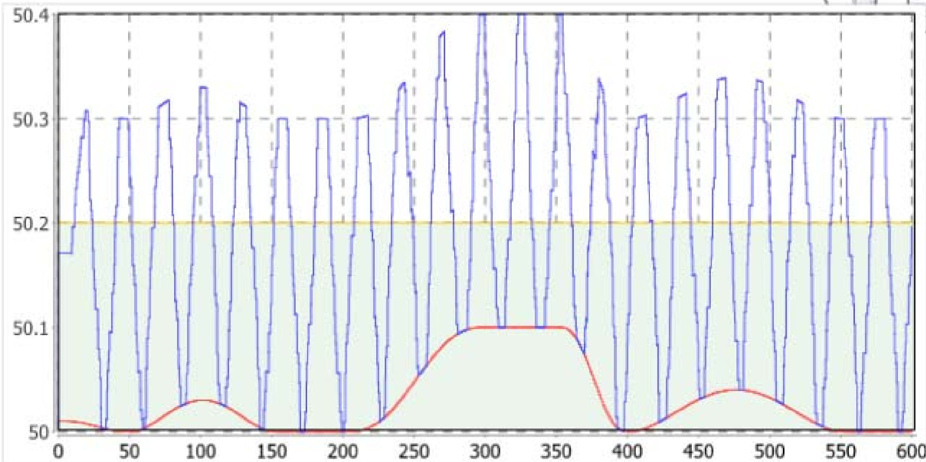
VDE-AR-N 4105: enforced since 2012
when `f > 50.2 Hz`
decrease output linear in `f`
when `f > 51.5 Hz`
switch off
when `f < 50.05 Hz` for 1 minute
switch on again

(simplified)

Current Control Strategies – Visualisation

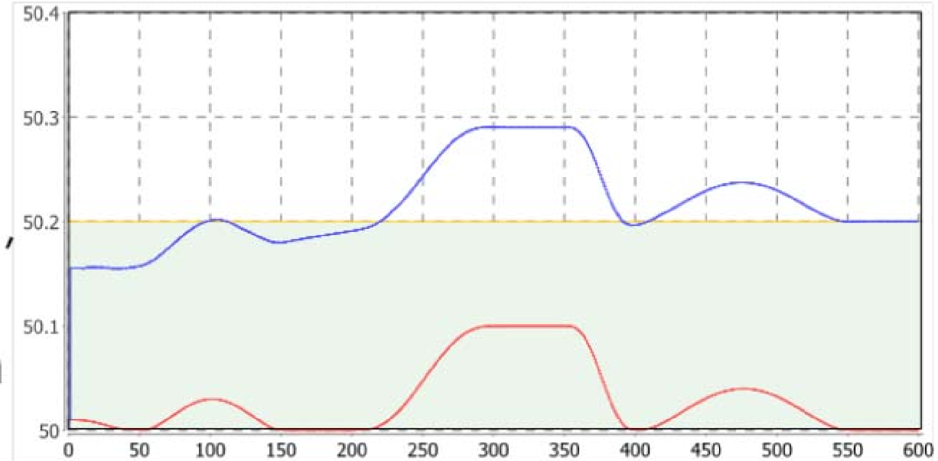
On-off controller

oscillating, unstable



Linear controller

no oscillation, dampening, no active stabilisation



New Control Strategies

Let's invent some new controllers!

*simple – stable – **randomised***

⇨ try to reuse computer network ideas and solutions

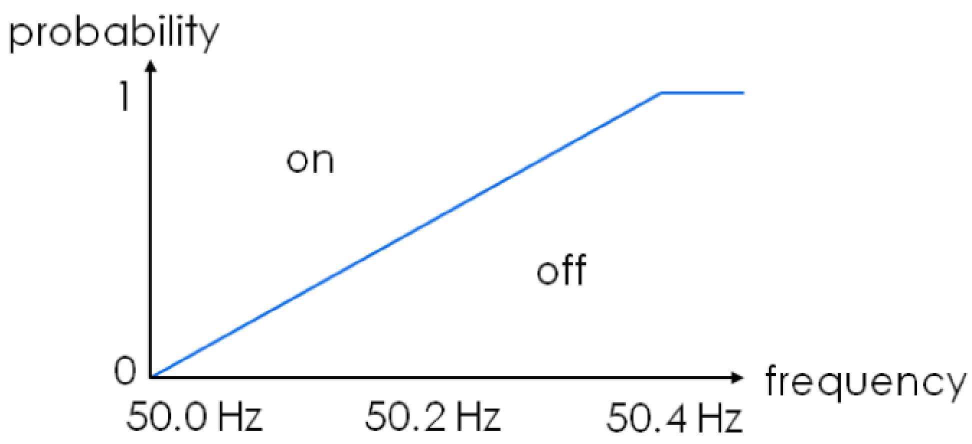
New Control Strategies

Frequency-dependent probabilistic switching

Used in: IEEE 802.11e

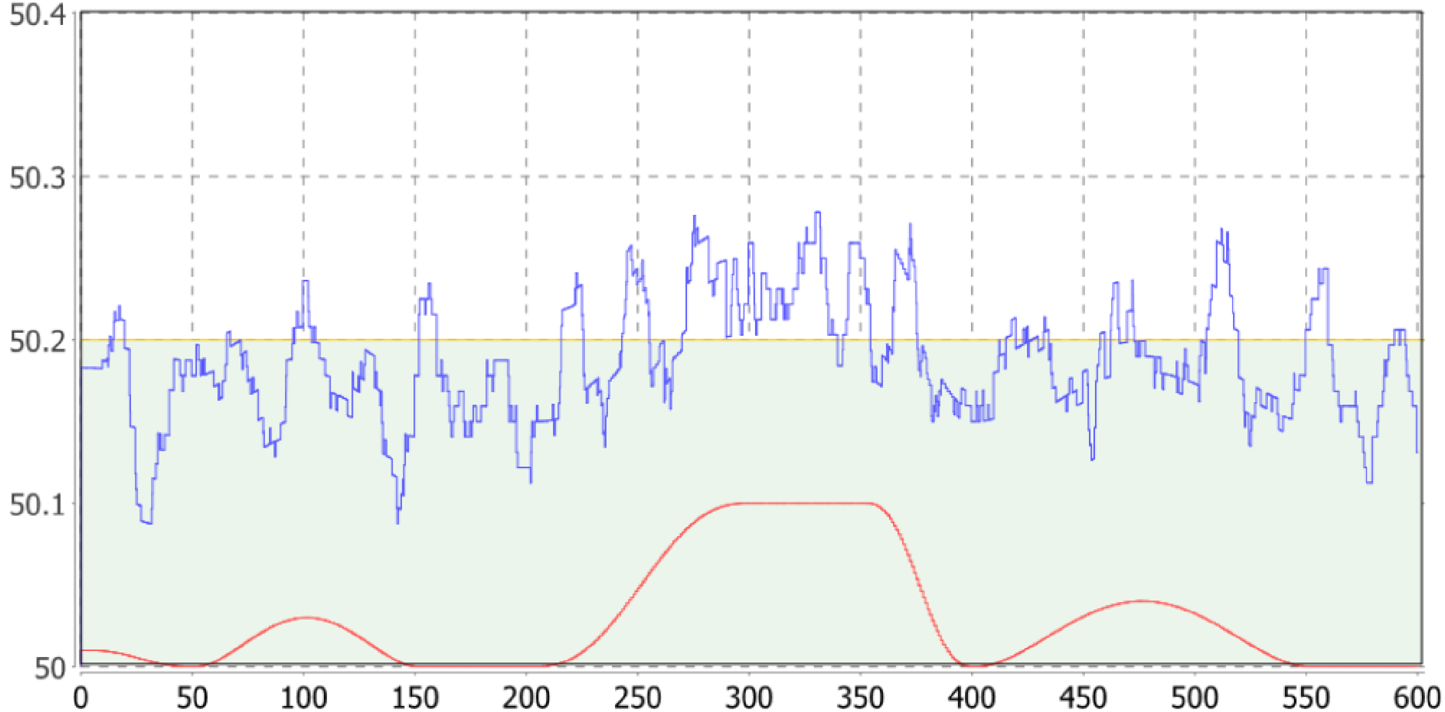
Goal: Adapt to system state, but not deterministically

Idea: Switch on or off with certain probability
that depends on the current frequency



New Control Strategies

Frequency-dependent probabilistic switching



New Control Strategies

Exponential backoff

Used in: Ethernet

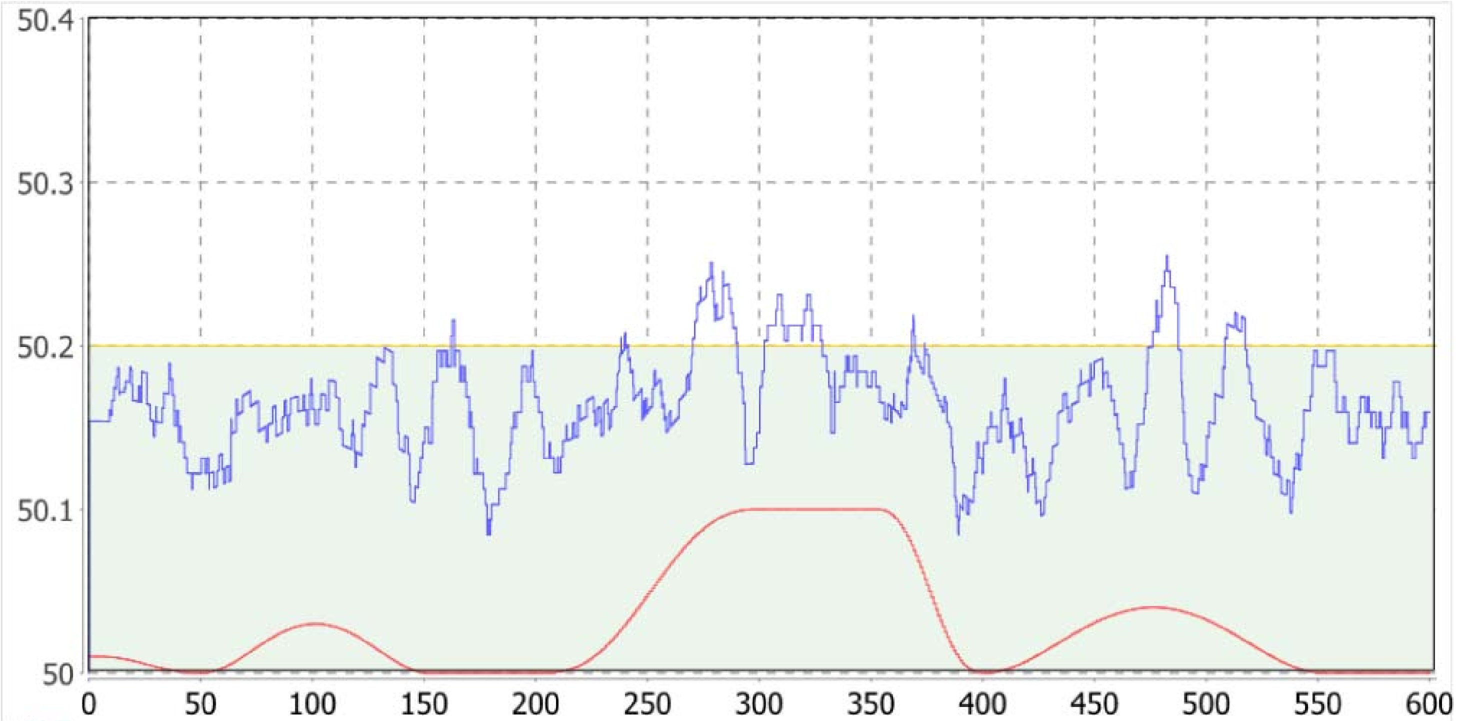
Goal: Mediate access to shared medium, decentralised

Idea: Try to send.
Collision? Wait time given by 2-sided die roll.
Try to send.
Collision? Wait time given by 4-sided die roll.
Try to send.
Collision? Wait time given by 8-sided die roll.
Try to send.
Collision? Wait time given by 16-sided die roll.
...

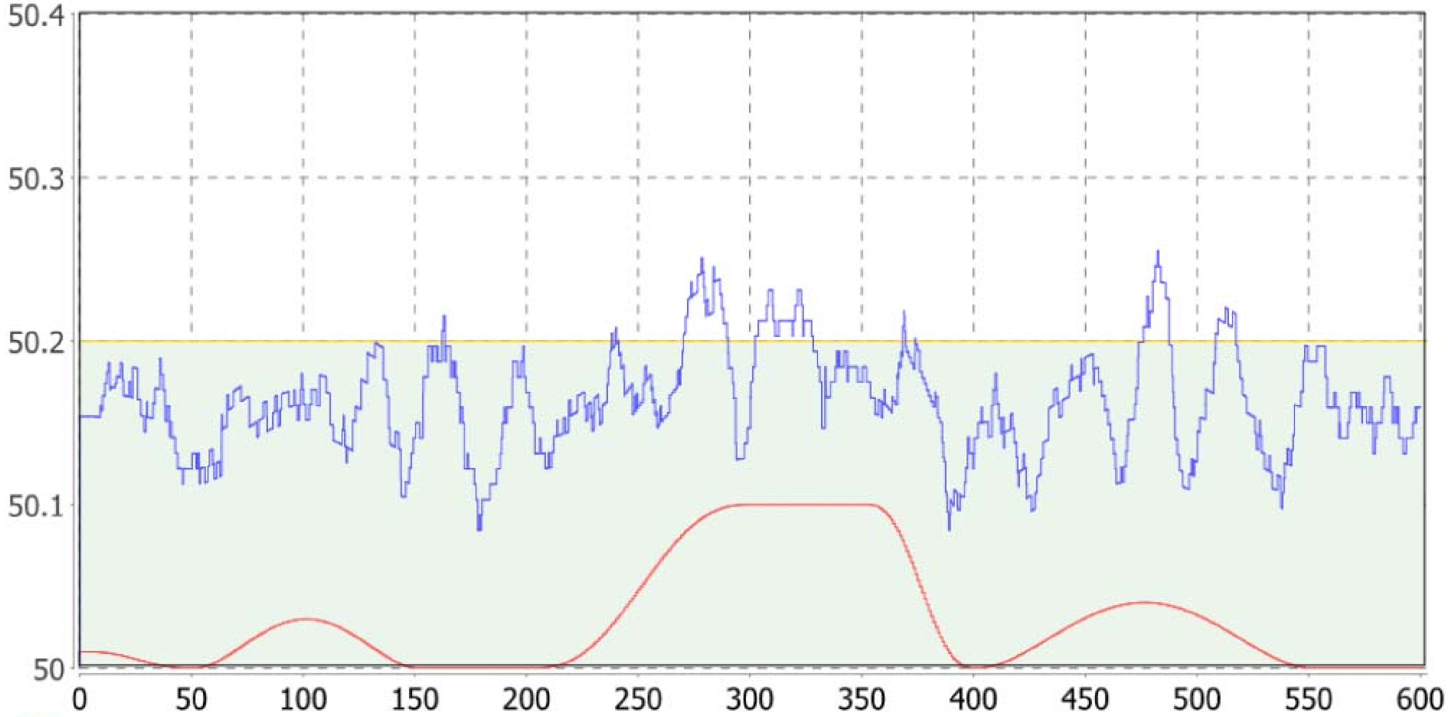
⇨ adjust wait time to number of participants

New Control Strategies

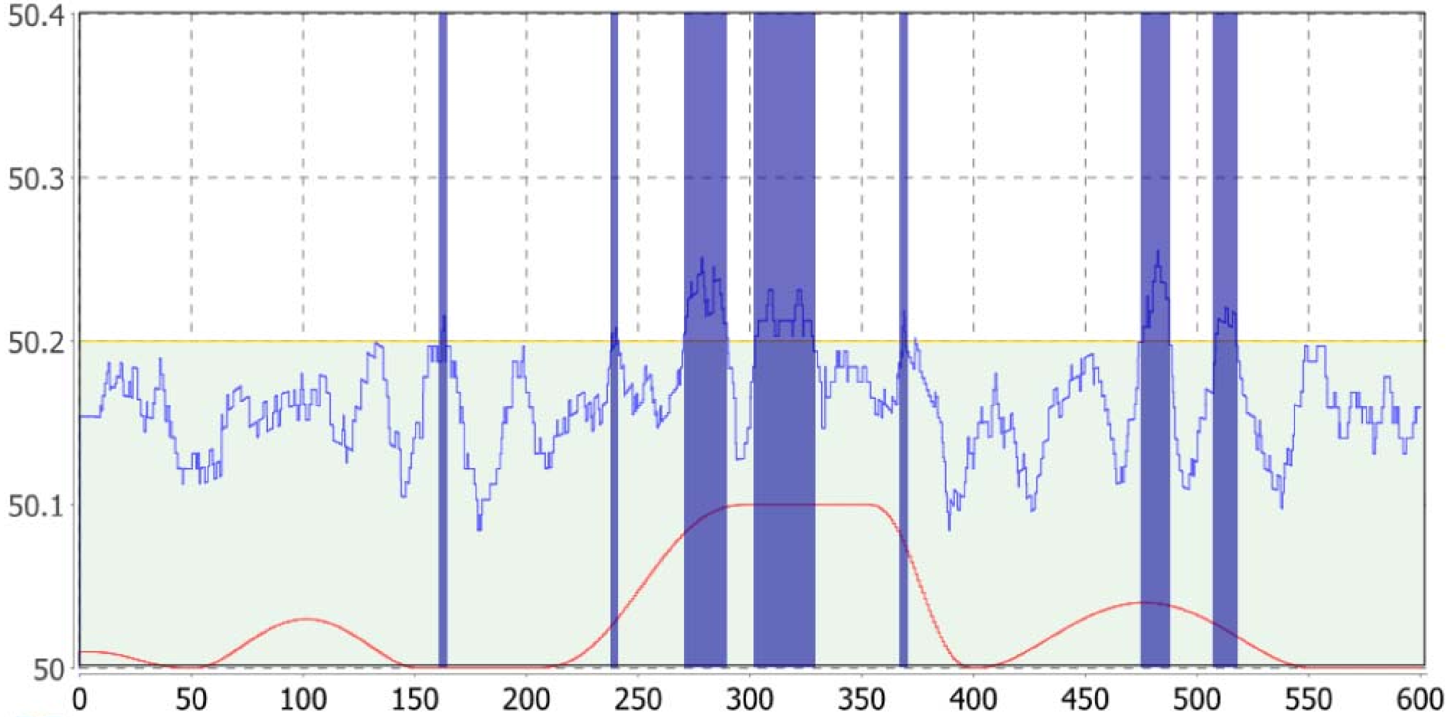
Frequency-dependent probabilistic switching
plus exponential backoff



Availability and Goodput

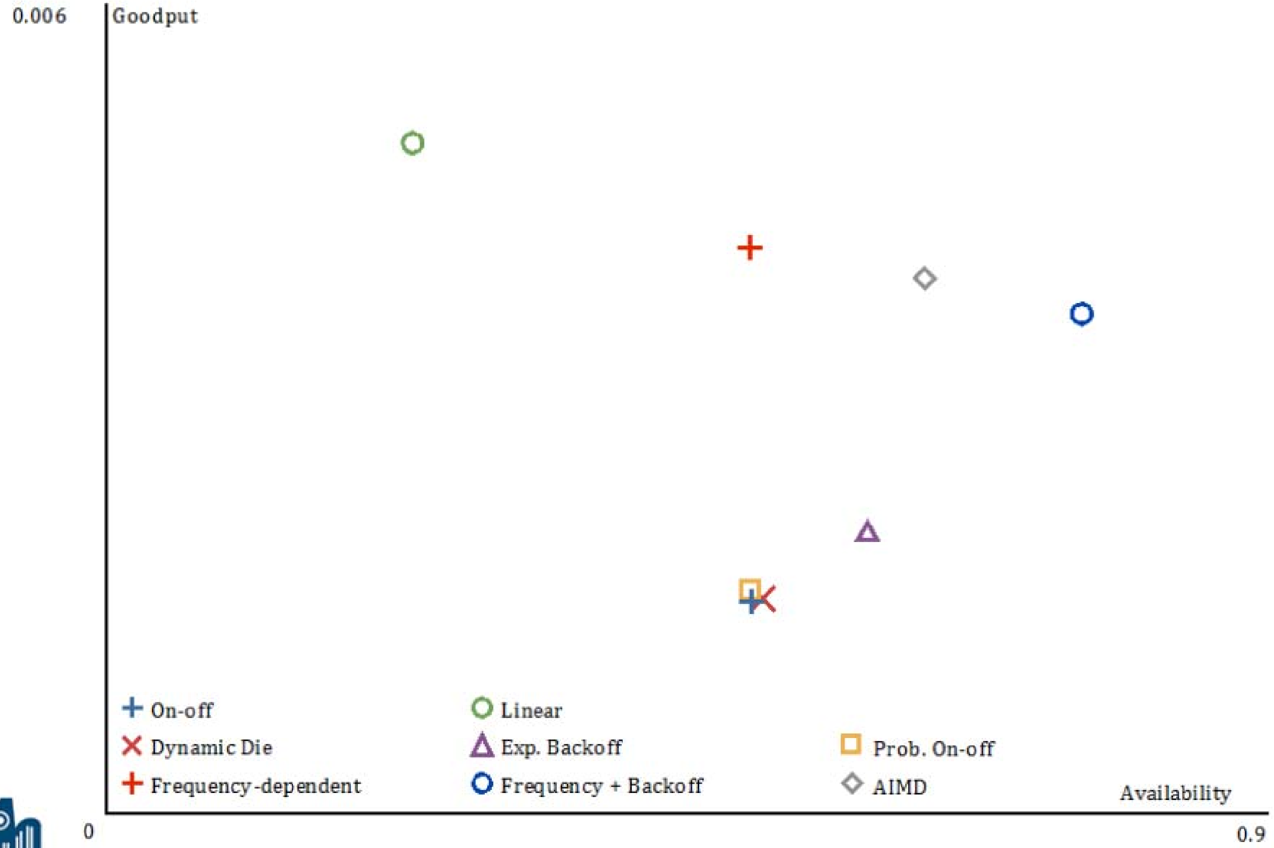


Availability and Goodput



Controller Model Checking Results

Availability vs. goodput



Controller Model Checking Results

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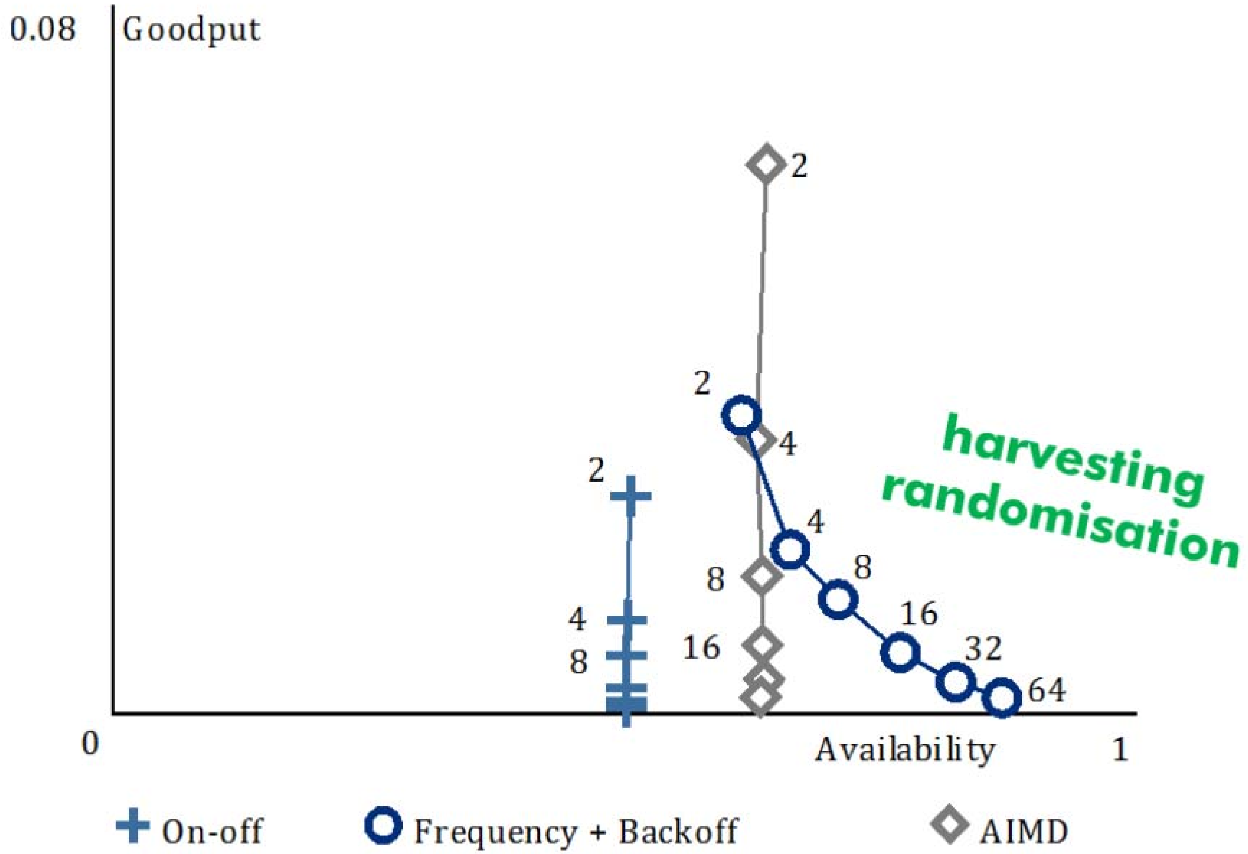
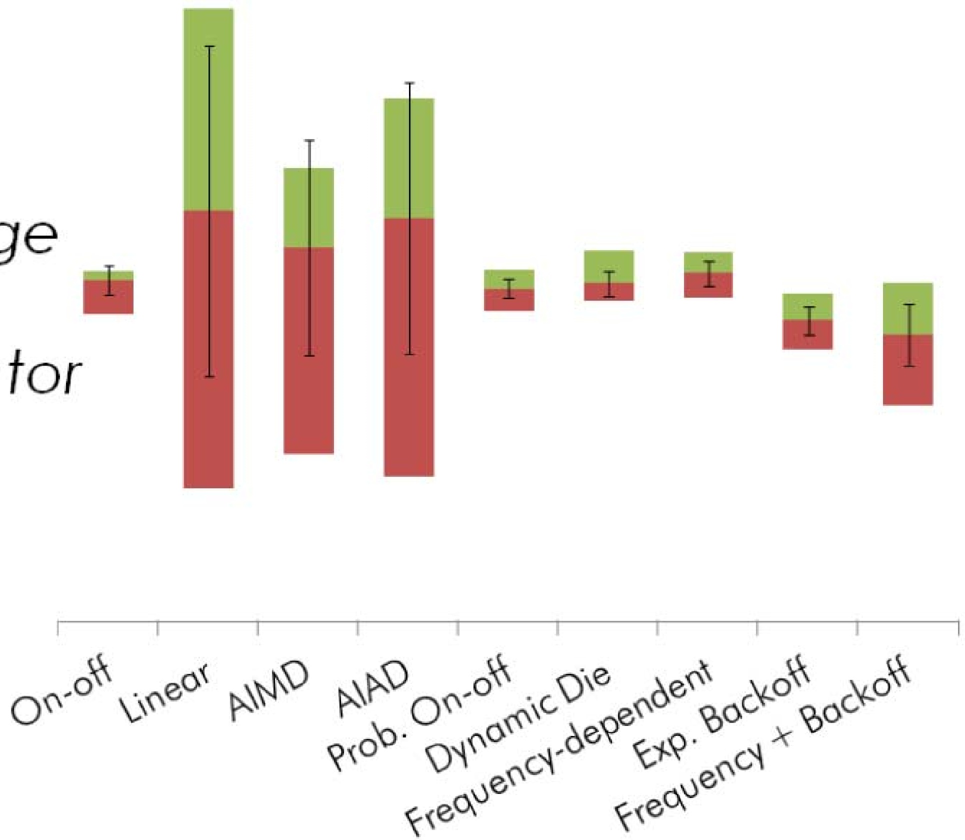


Controller Model Checking Results

Fairness

max/min/average output per generator

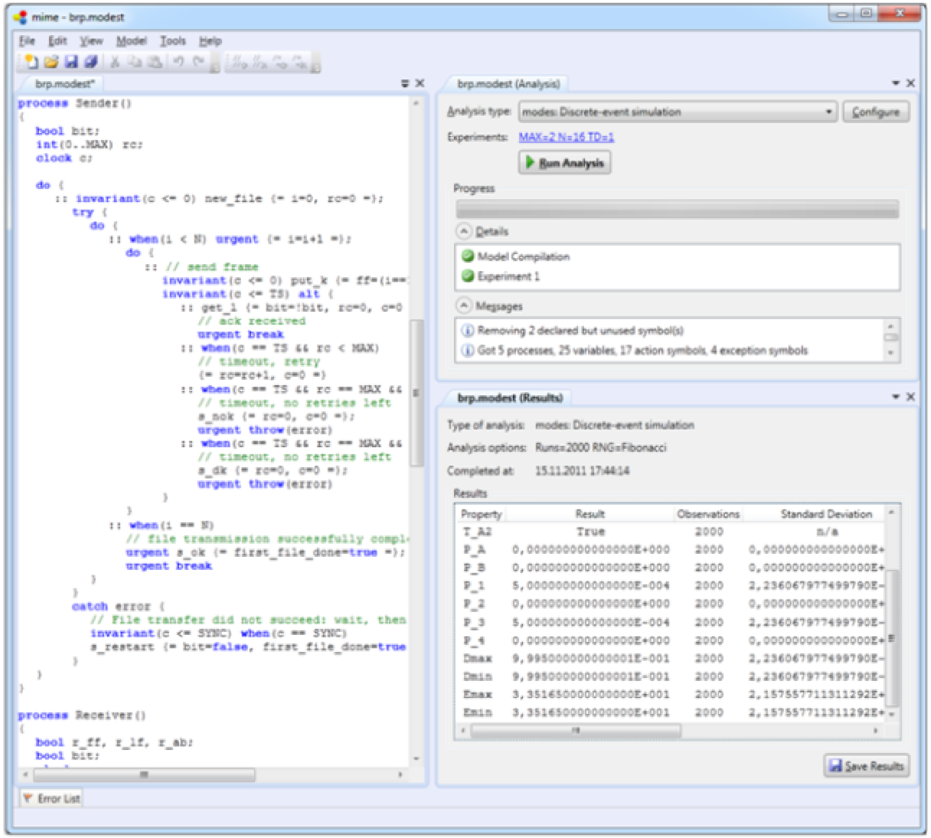


Can I also do this?
Do I need to develop my own simulator?

You can do this.

Use our 'simulator'.

It is a
model checker,
actually.



www.modestchecker.net

Modest

A Modelling and Description Language
for Stochastic Timed Systems

Language features:

Variables and assignments

bool, int, arrays

Processes and recursion

Clocks

Exception handling

Rewards/costs

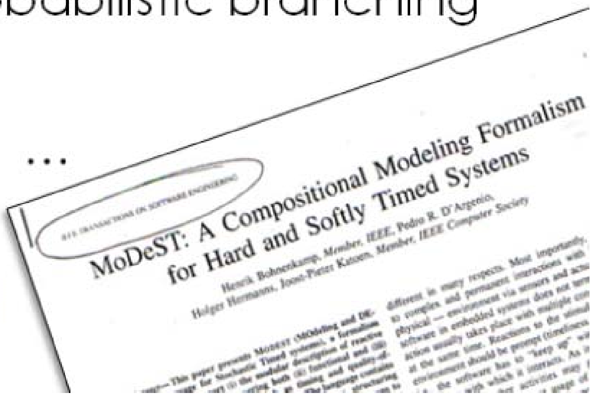
Deadlines & invariants

Probabilistic branching

Random variable sampling

...

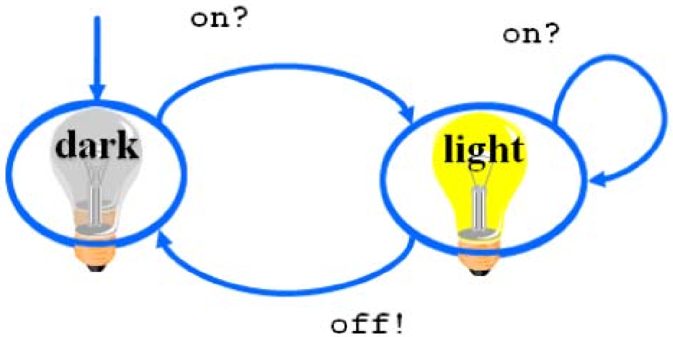
Bohnenkamp, D'Argenio, Hermanns, Katoen:
IEEE TSE 32 (10), 2006


MoDeST: A Compositional Modeling Formalism for Hard and Softly Timed Systems
Henrik Bohnenkamp, Member, IEEE, Pedro R. D'Argenio,
Holger Hermanns, Joost-Pieter Katoen, Member, IEEE Computer Society

Quantitative Models

A quantitative automata family

Finite Automata



FA

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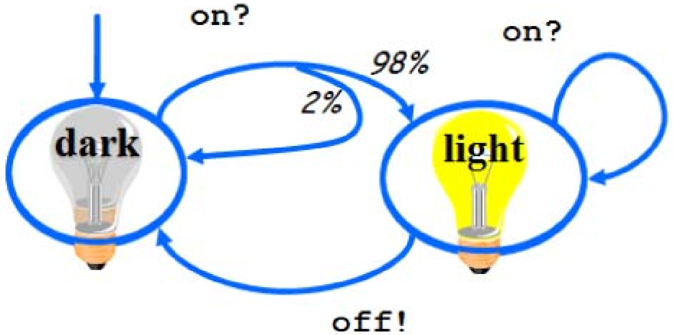

FA

MC

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A quantitative automata family

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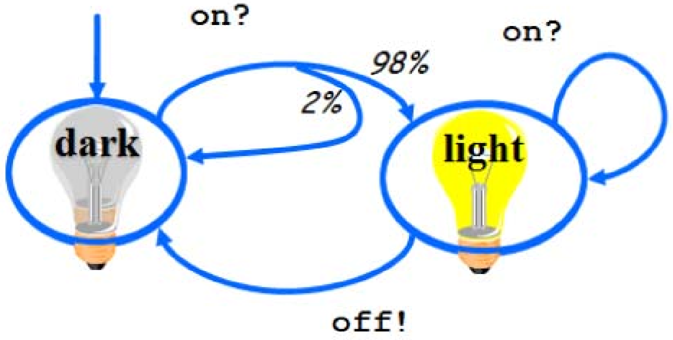
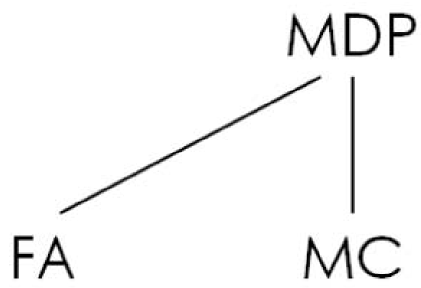
Markov Chains

Markov Decision Processes





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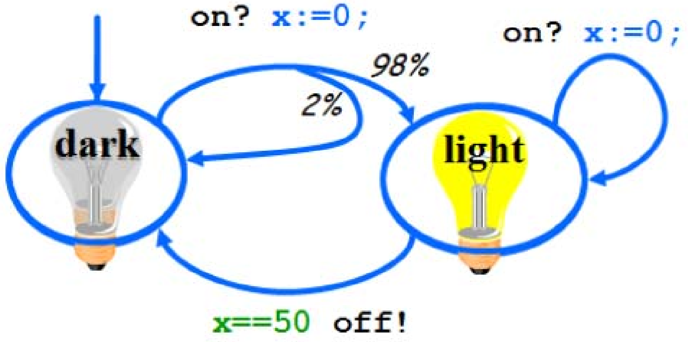
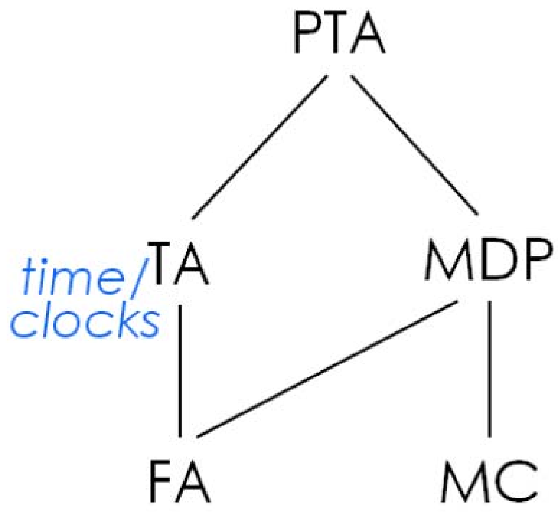
Markov Decision Processes

Probabilistic Timed Automata





Quantitative Models and Their Compositions

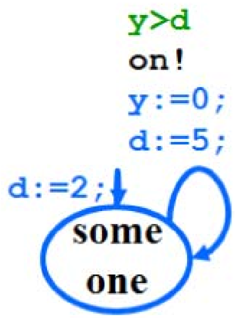
A quantitative automata family

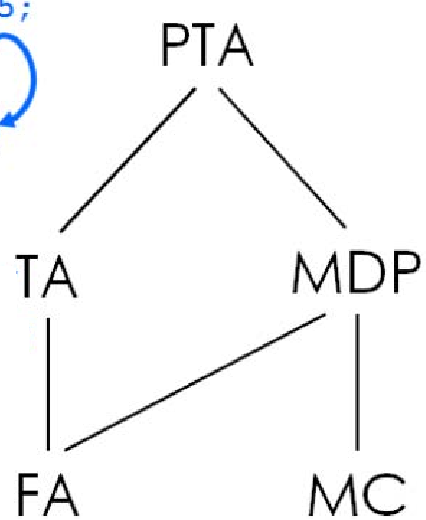
Finite Automata

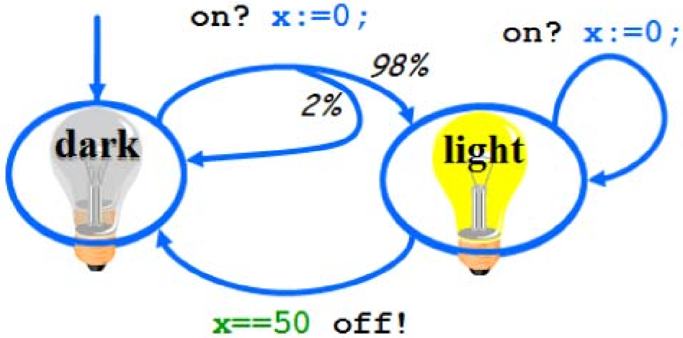
Markov Chains

Markov Decision Processes

Probabilistic Timed Automata







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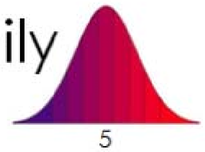
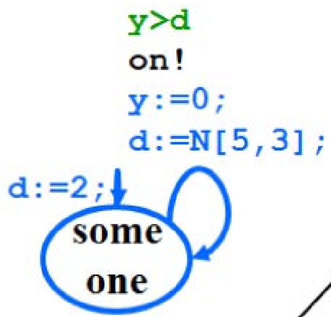
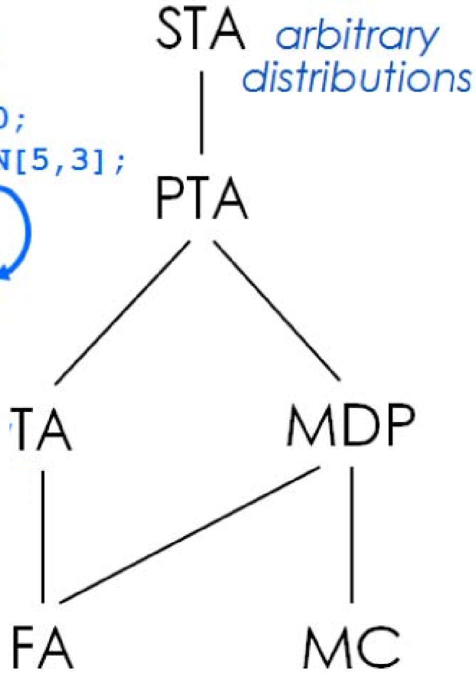
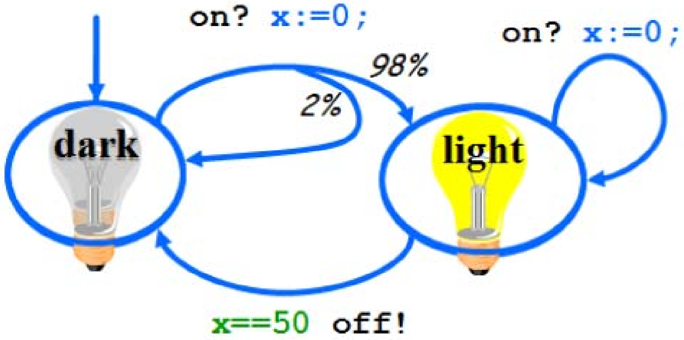
Probabilistic Timed Automata

Stochastic Timed Automata



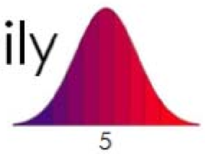






Quantitative Models and Their Compositions

A quantitative automata family



Finite Automata

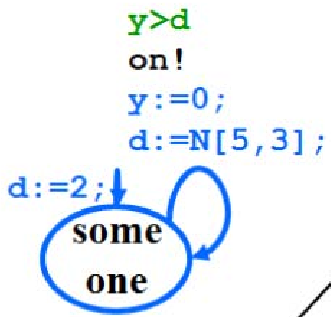
Markov Chains

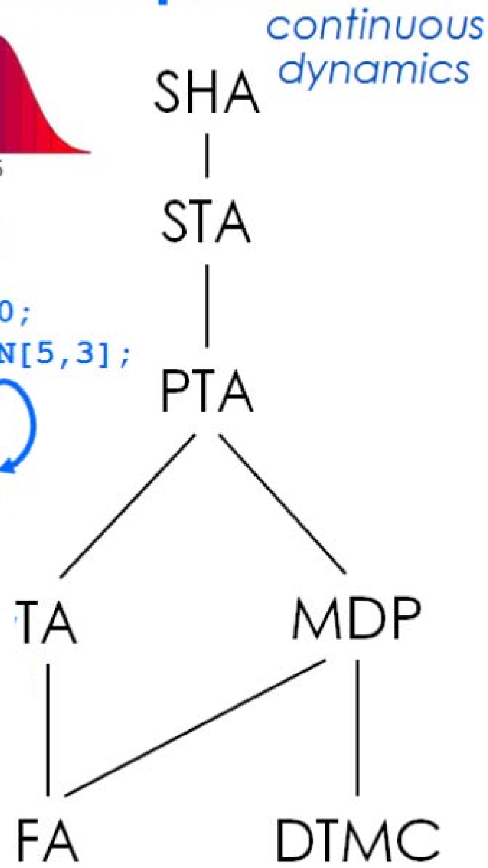
Markov Decision Processes

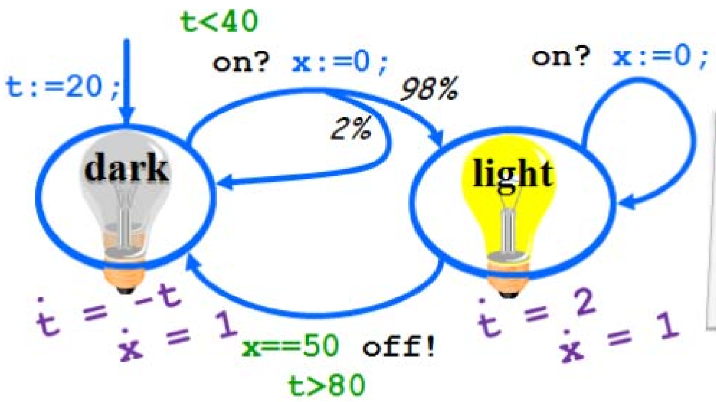
Probabilistic Timed Automata

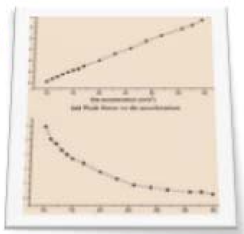
Stochastic Timed Automata

Stochastic Hybrid Automata

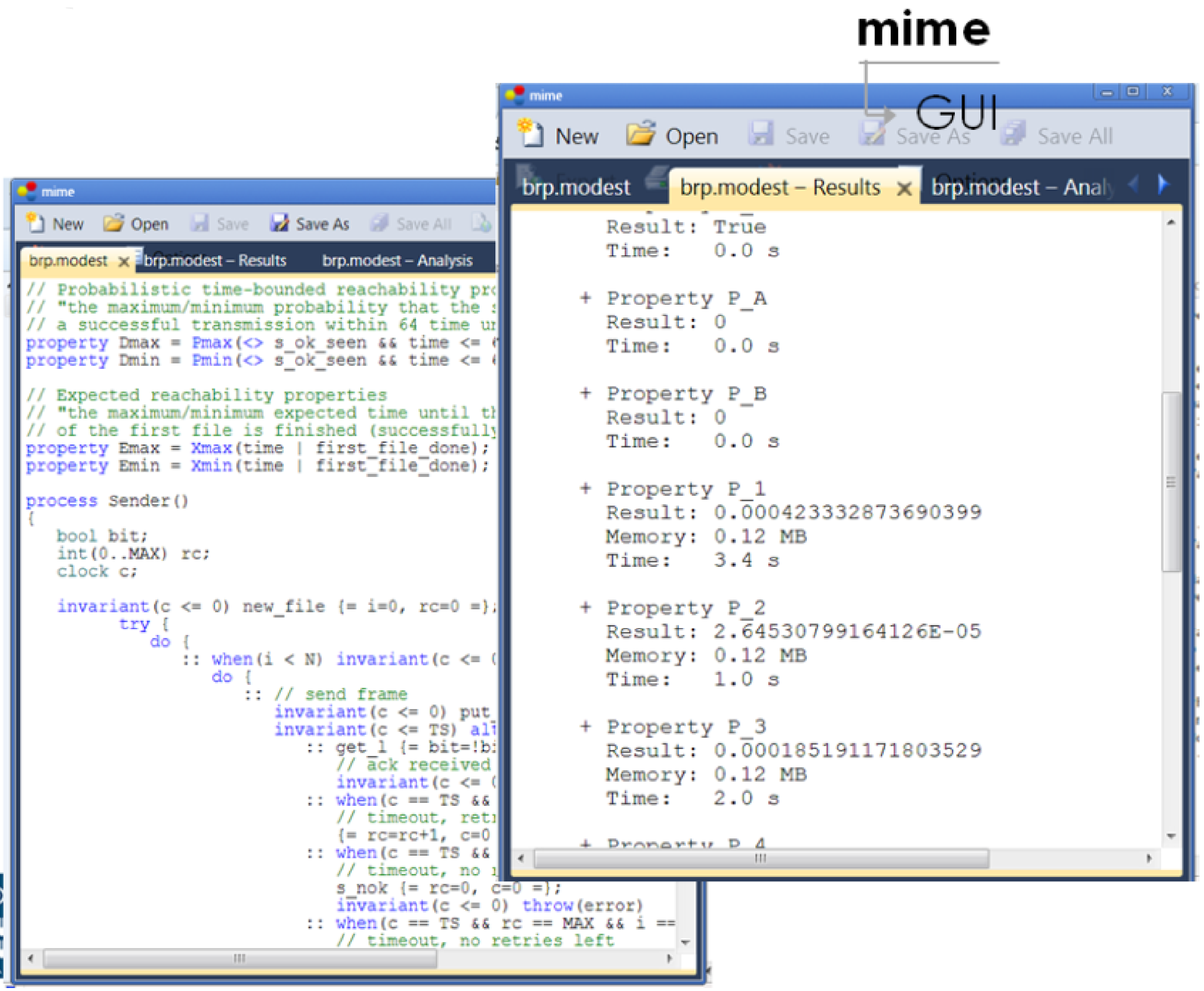








The Modest Toolset



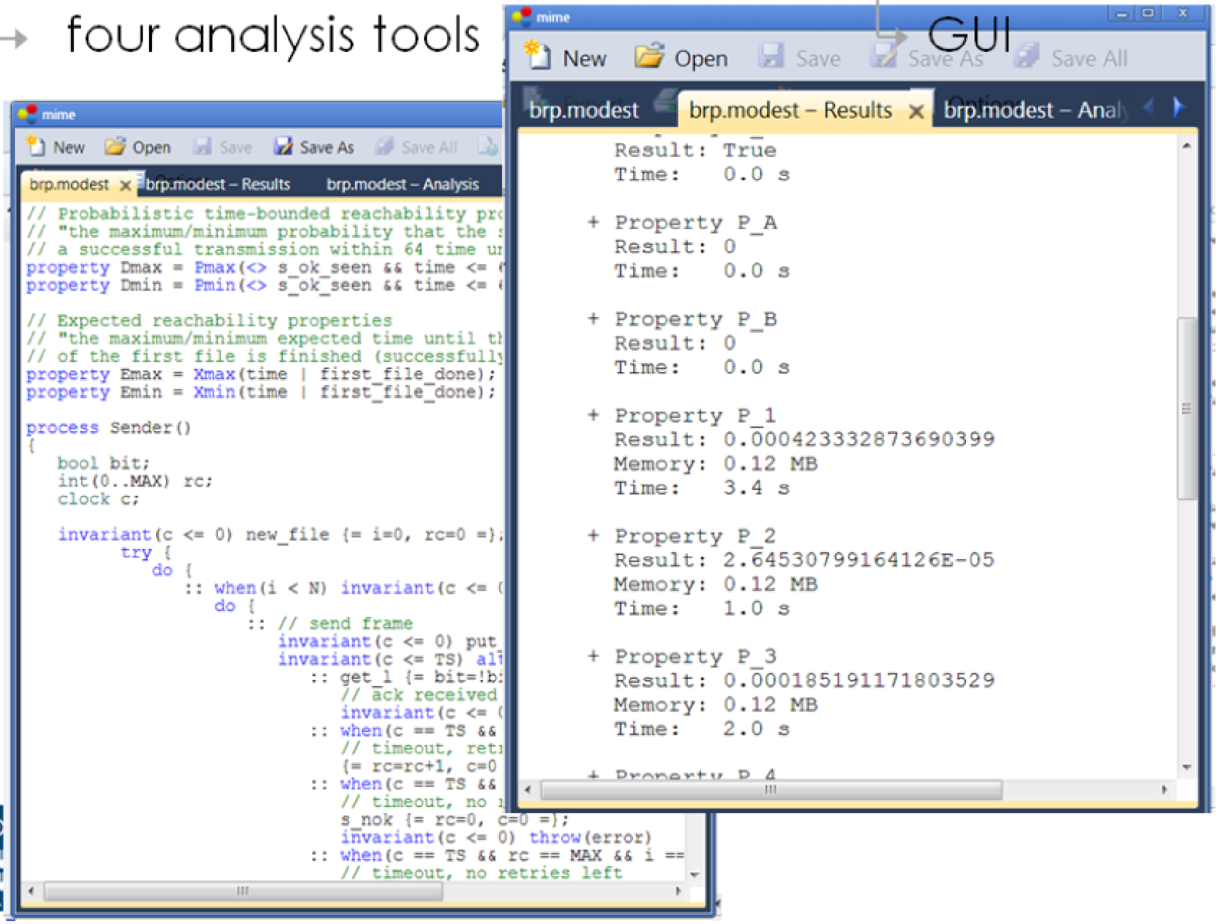
The Modest Toolset

mctau – mcpta – prohver – modes – mime – mosta

four analysis tools

GUI

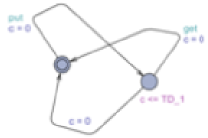
semantics

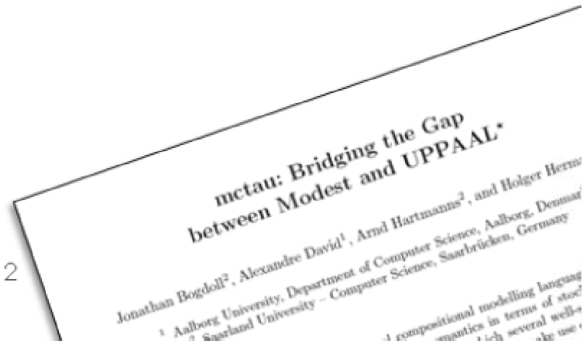


The Modest Toolset

mctau – mcpta – prohver – modes – mime – mosta

mctau Model-checking for TA using UPPAAL
Export from Modest to UPPAAL with layout
Overapproximation of probabilistic choices




mctau: Bridging the Gap
between Modest and UPPAAL*

Jonathan Bogdoll[2], Alexandre David[1], Arnd Hartmanns[2], and Holger Herm

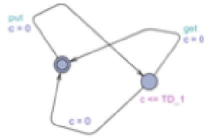
[1] Aalborg University, Department of Computer Science, Aalborg, Denma
[2] Saarland University – Computer Science, Saarbrücken, Germany

Bogdoll, David, Hartmanns, Hermanns: SPIN 2012

19 Aug 2013

The Modest Toolset

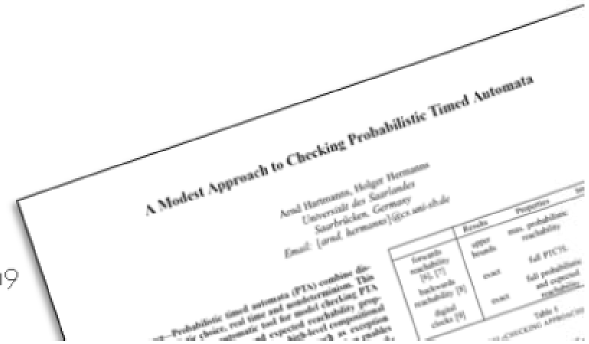
mctau – mcpta – prohver – modes – mime – mosta



mctau Model-checking for TA using UPPAAL
Export from Modest to UPPAAL with layout
Overapproximation of probabilistic choices

mcpta Model-checking for PTA using PRISM
Export from Modest to Guarded Commands

Hartmanns, Hermanns: QEST 2009


A Modest Approach to Checking Probabilistic Timed Automata

Arnd Hartmanns, Holger Hermanns
Universität des Saarlandes
Saarbrücken, Germany
Email: {arnd, hermanns}@cs.uni-sb.de

The Modest Toolset

mctau – mcpta – prohver – modes – mime – mosta

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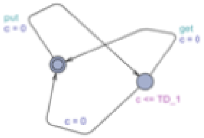
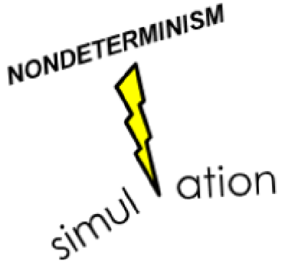
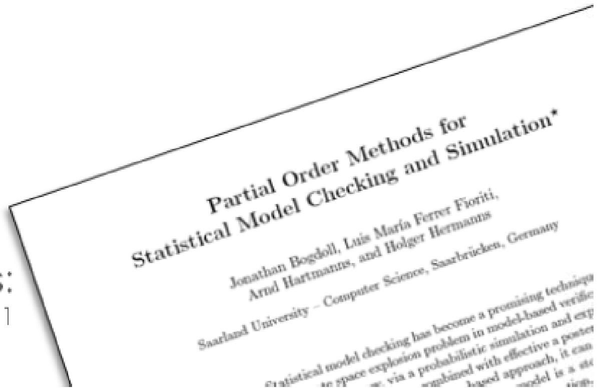


mcpta Model-checking for PTA using PRISM
Export from Modest to Guarded Commands

modes Simulation & Statistical Model Checking for STA
with spurious nondeterminism



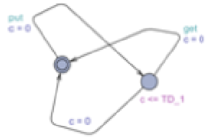
Bogdoll, Ferrer Fioriti, Hartmanns, Hermanns:
FMOODS/FORTE 2011



The Modest Toolset

mctau – mcpta – prohver – modes – mime – mosta

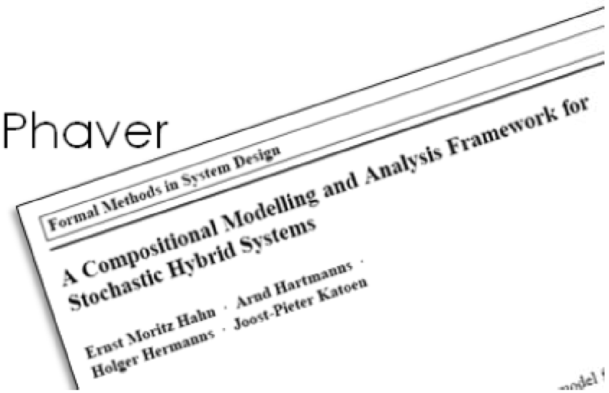
mctau Model-checking for TA using UPPAAL
Export from Modest to UPPAAL with layout
Overapproximation of probabilistic choices



mcpta Model-checking for PTA using PRISM
Export from Modest to Guarded Commands

modes Simulation & Statistical Model Checking for STA
with spurious nondeterminism

prohver Safety Verification for SHA
Using (modified) HA Solver Phaver

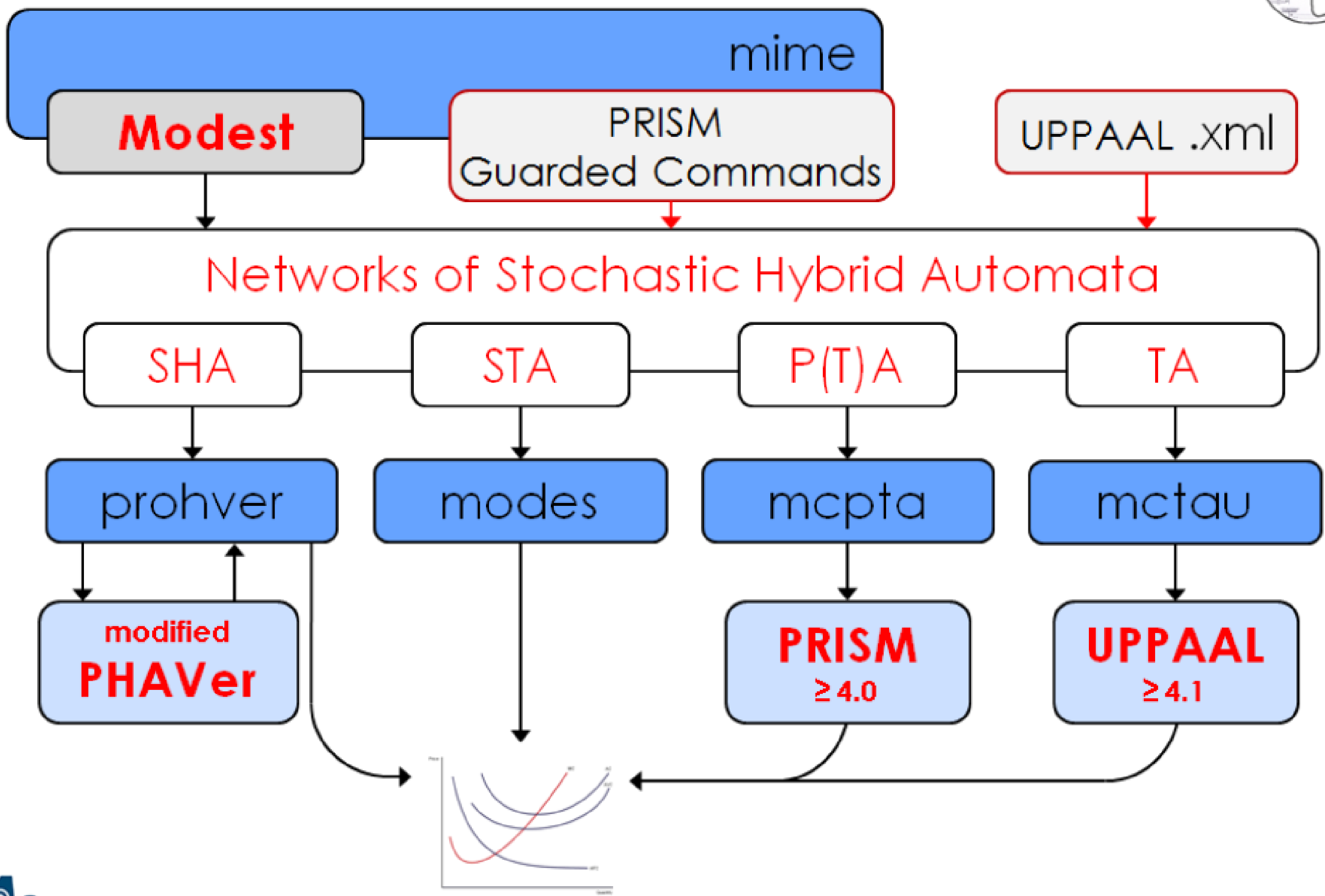

Formal Methods in System Design

A Compositional Modelling and Analysis Framework for Stochastic Hybrid Systems

Ernst Moritz Hahn · Arnd Hartmanns · Holger Hermanns · Joost-Pieter Katoen

Hahn, Hartmanns, Hermanns, Katoen:
FMSD 43(2): 191-232 (2013)

The Modest Toolset

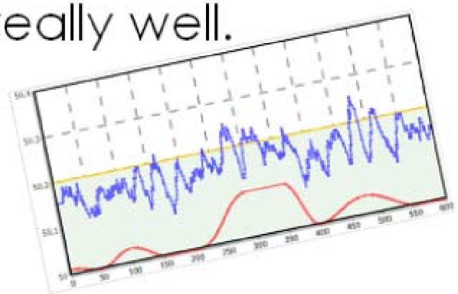


Conclusion

Photovoltaic microgeneration creates new challenges.

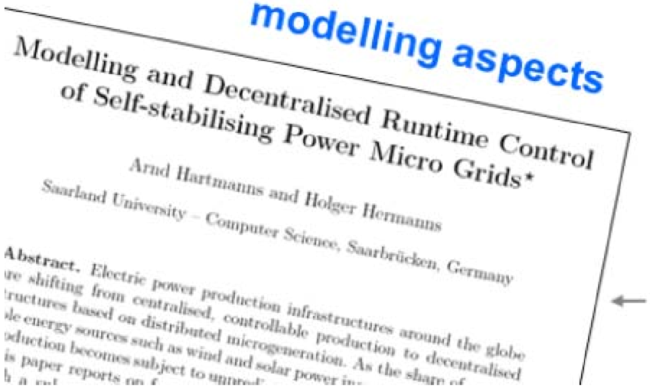
Modest Checking helps evaluation of new approaches.

Some of the new control strategies work really well.



Bonus: No privacy concerns!
No exploits!

modelling aspects



Modelling and Decentralised Runtime Control of Self-stabilising Power Micro Grids*

Arnd Hartmanns and Holger Hermanns

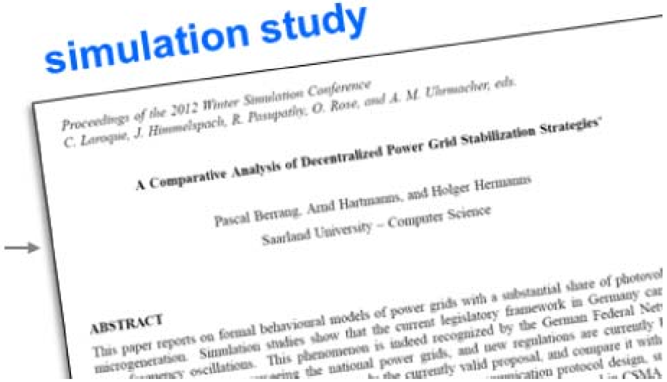
Saarland University – Computer Science, Saarbrücken, Germany

Abstract. Electric power production infrastructures around the globe are shifting from centralised, controllable production to decentralised ... based on distributed microgeneration. As the share of ... energy sources such as wind and solar power ... production becomes subject to unpredi... this paper reports on f...

WSC 2012 →

← ISoLA 2012

simulation study



Proceedings of the 2012 Winter Simulation Conference
C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, eds.

A Comparative Analysis of Decentralized Power Grid Stabilization Strategies

Pascal Berrang, Arnd Hartmanns, and Holger Hermanns
Saarland University – Computer Science

ABSTRACT

This paper reports on formal behavioural models of power grids with a substantial share of photovol... microgeneration. Simulation studies show that the current legislatory framework in Germany ca... frequency oscillations. This phenomenon is indeed recognized by the German Federal Net... the national power grids, and new regulations are currently ... the currently valid proposal, and compare it with ... communication protocol design, ...