

From Power Domains to Power Grids

Holger Hermanns

Saarland University



joint work with

Pascal Berrang, Arnd Hartmanns



Challenge



19 Aug 2013

HH@HH

Electrifying Challenge



Germany

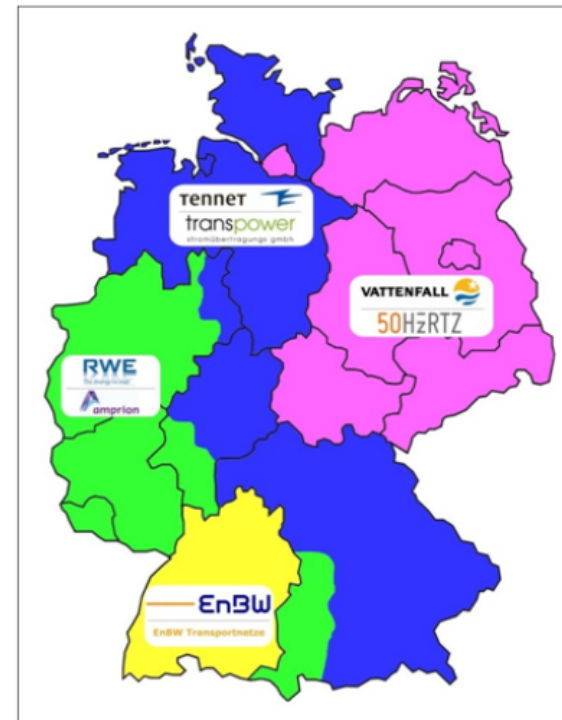
- gives priority to renewable sources
- rewards renewable energy above market price
- drops nuclear energy after Fukushima incident

More challenges:



Sweden, UK, France, Fiji, ...

19 Aug 2013



source: <http://www.wikipedia.org>

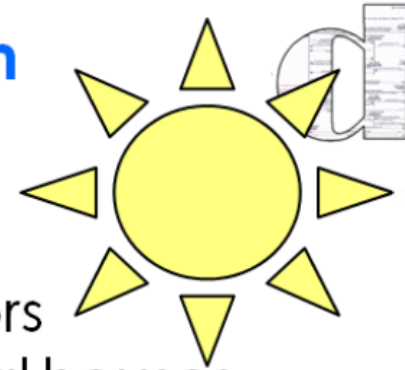
Power Grids and Microgeneration

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!



19 Aug 2013

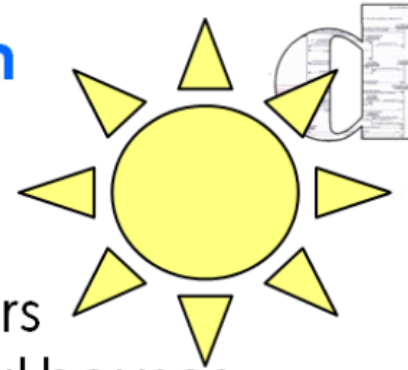


Power Grids and Microgeneration

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!

*German peak load:
around 80 GW*



19 Aug 2013

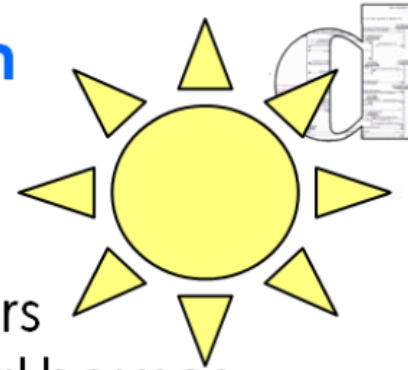


Power Grids and Microgeneration

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!

Is it?

*>60% renewable on
June 16, 2013*

*German peak load:
around 80 GW*

European grid:

15 GW \approx 1 Hz

Target: [49.8, 50.2] Hz



19 Aug 2013



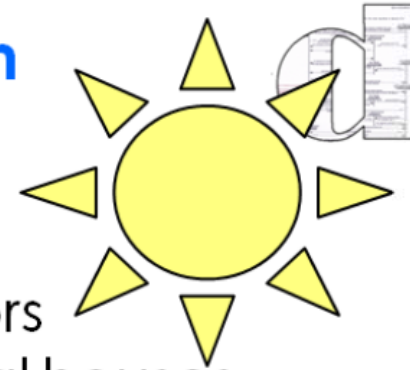
Power Grids and Microgeneration

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



19 Aug 2013

Current Control Strategies



On-off controller EN 50438: enforced in 2007
when $f > 50.2 \text{ Hz}$
switch off

about 380 thousand on-off controllers on German rooftops now

Linear controller

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

(simplified)

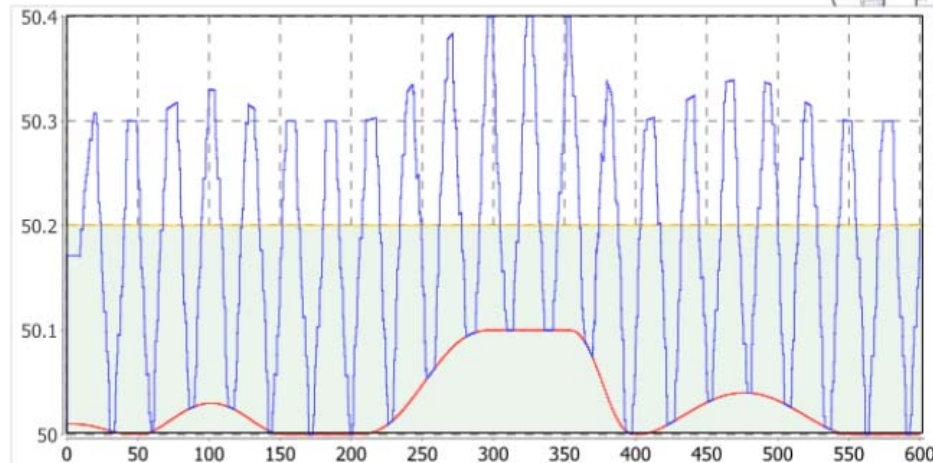


19 Aug 2013

Current Control Strategies – Visualisation

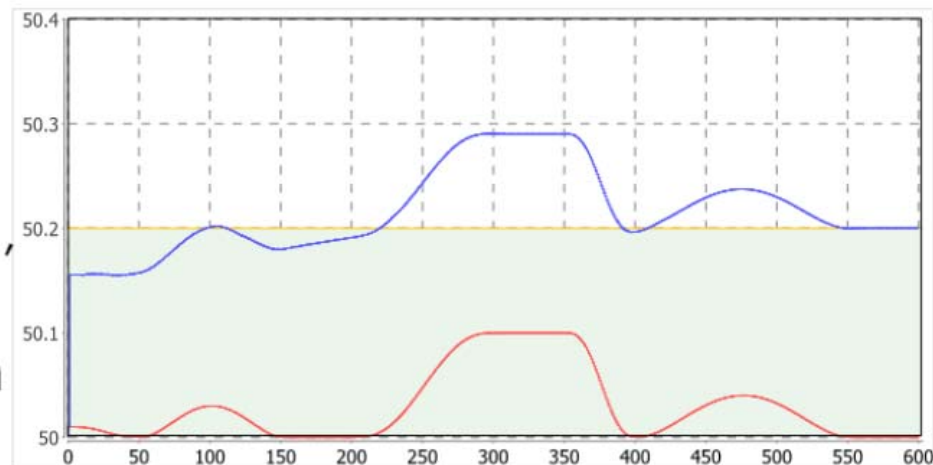
On-off controller

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



19 Aug 2013

New Control Strategies

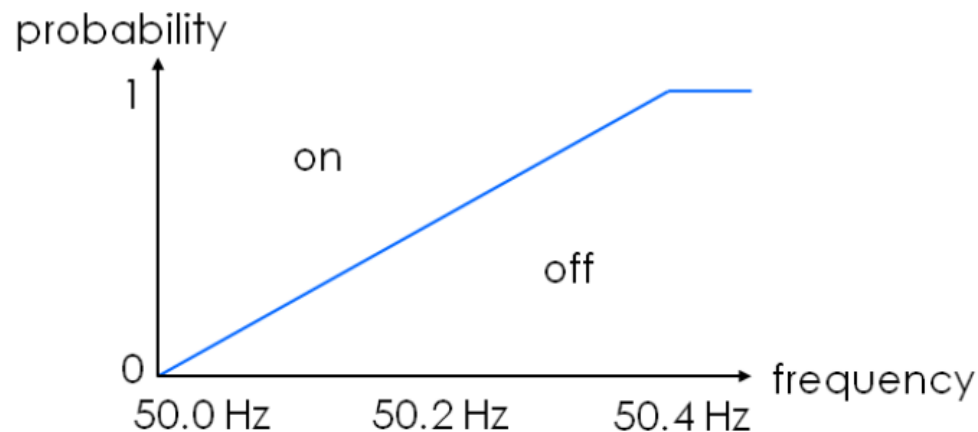


Frequency-dependent probabilistic switching

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

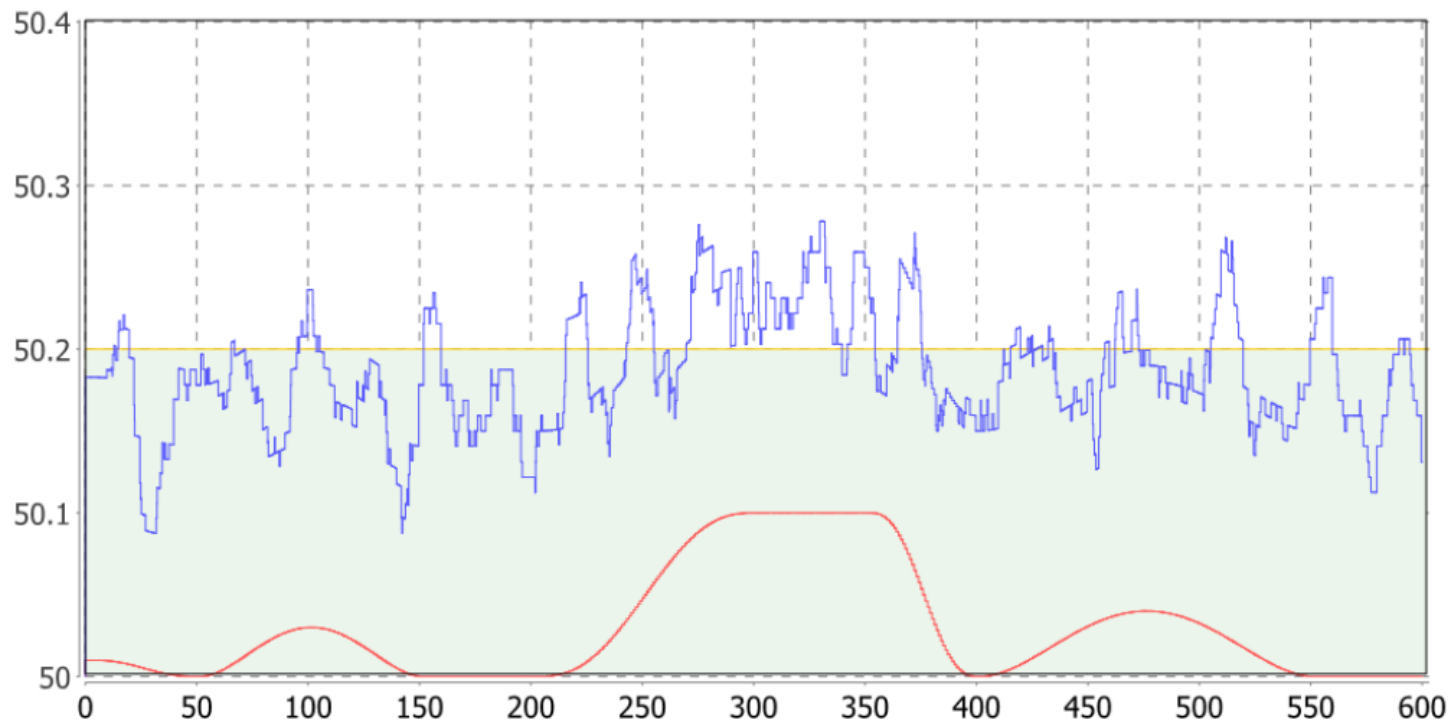


19 Aug 2013

New Control Strategies



Frequency-dependent probabilistic switching



19 Aug 2013

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

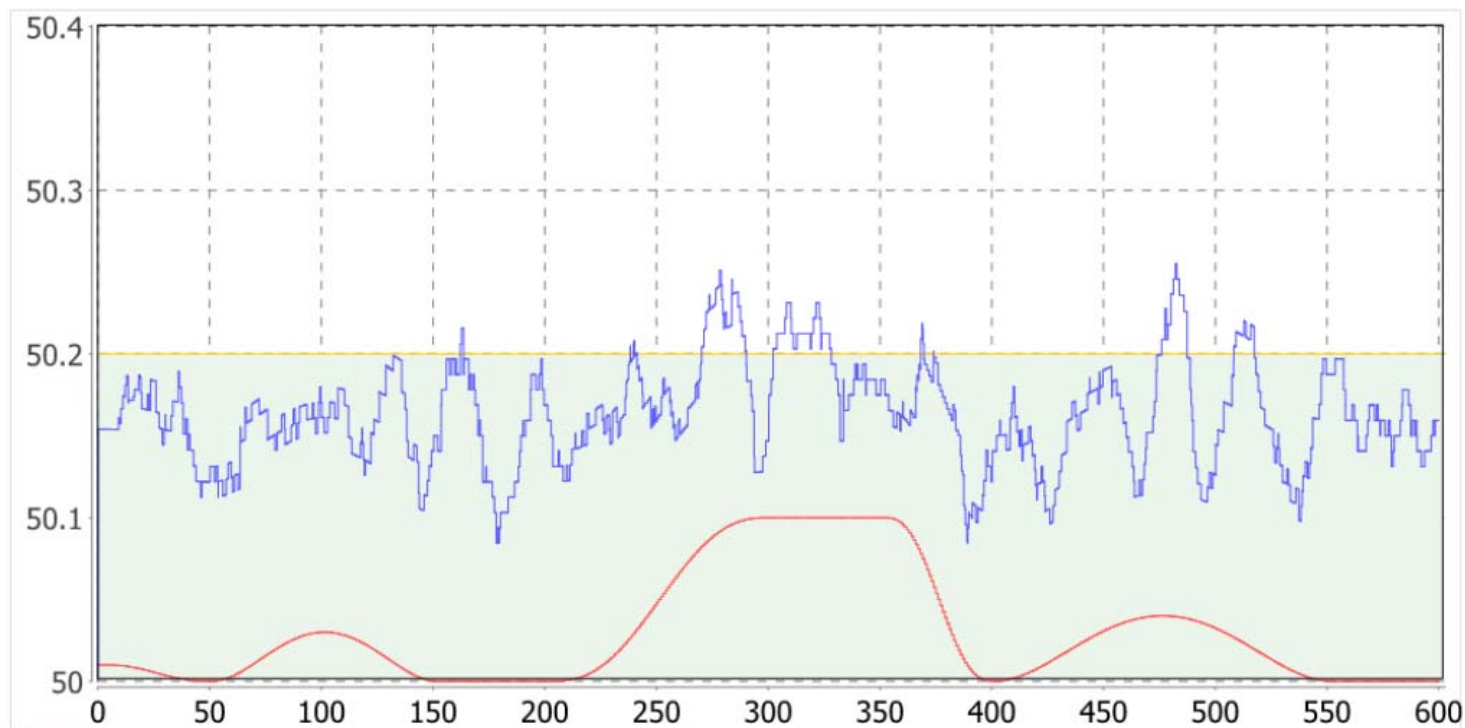


19 Aug 2013

New Control Strategies

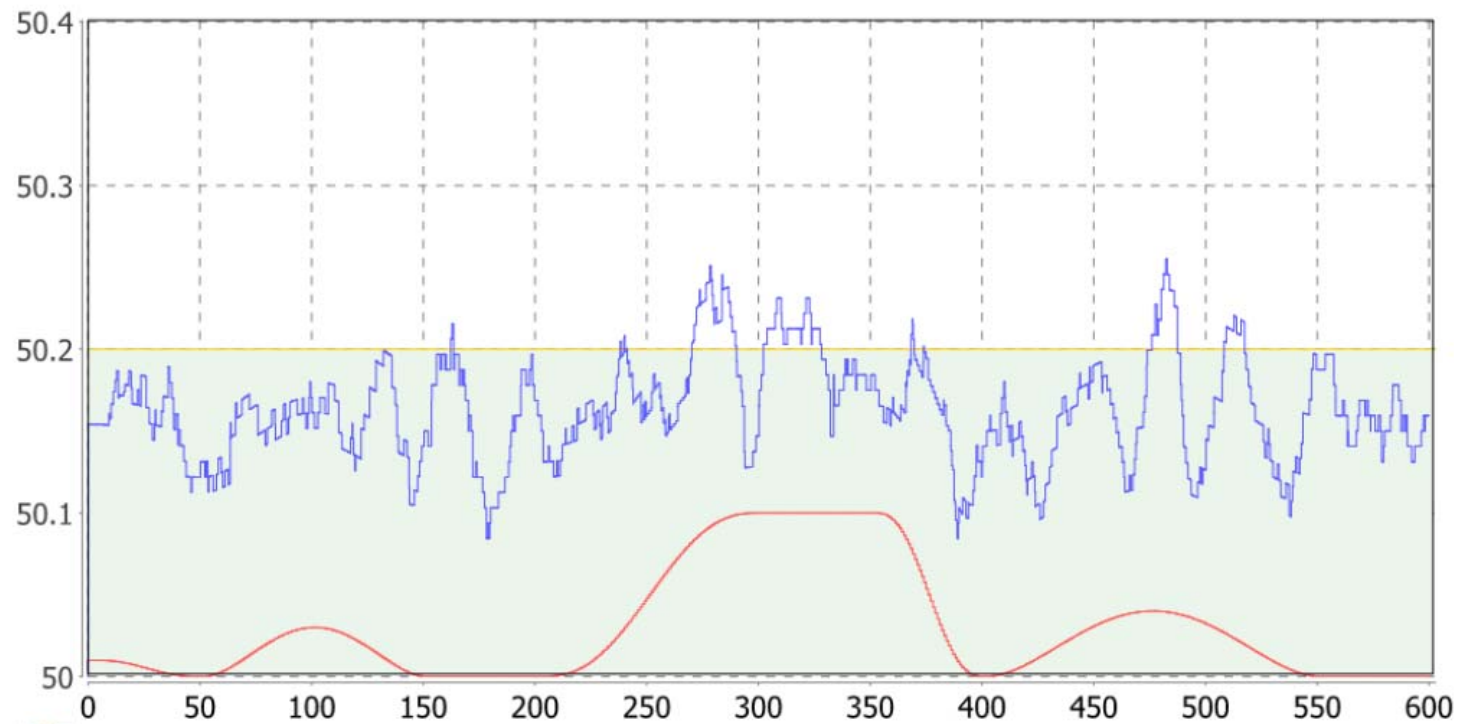


Frequency-dependent probabilistic switching
plus exponential backoff



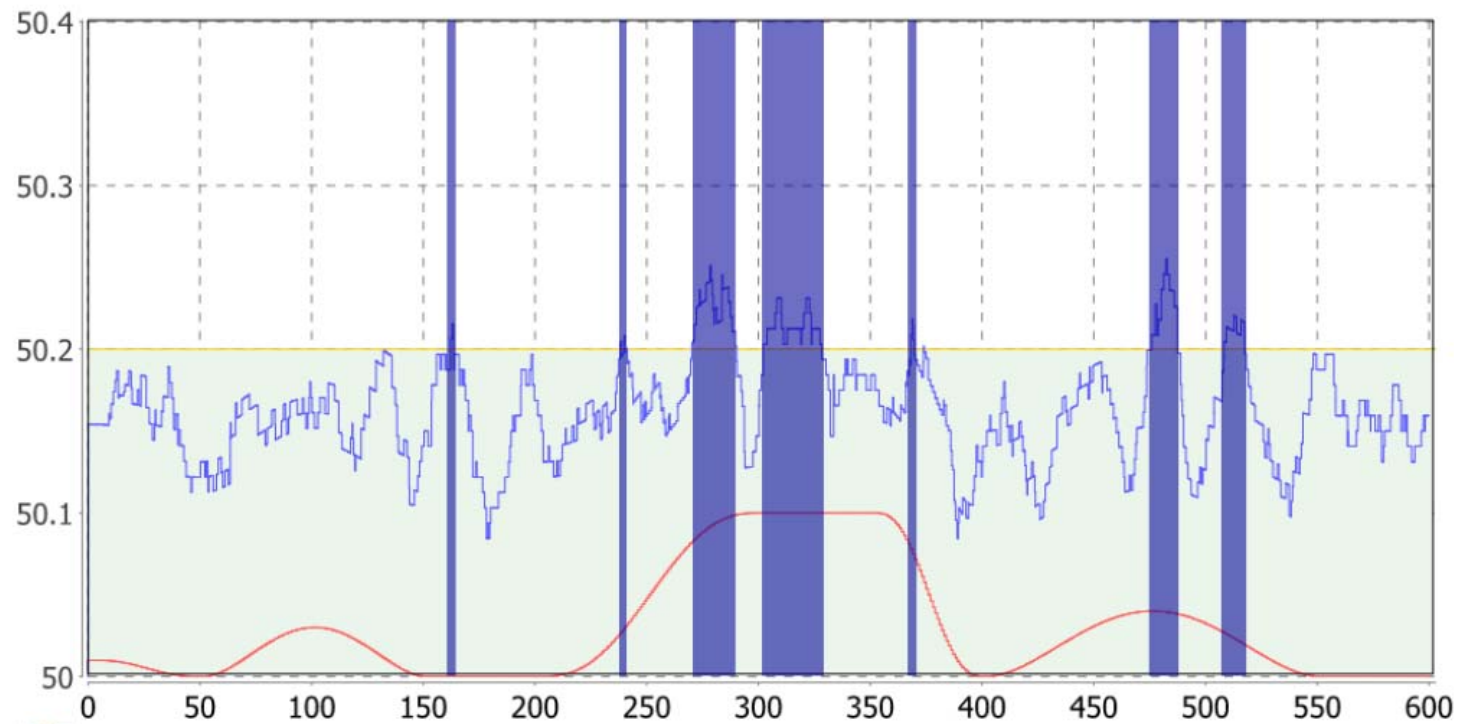
19 Aug 2013

Availability and Goodput



19 Aug 2013

Availability and Goodput

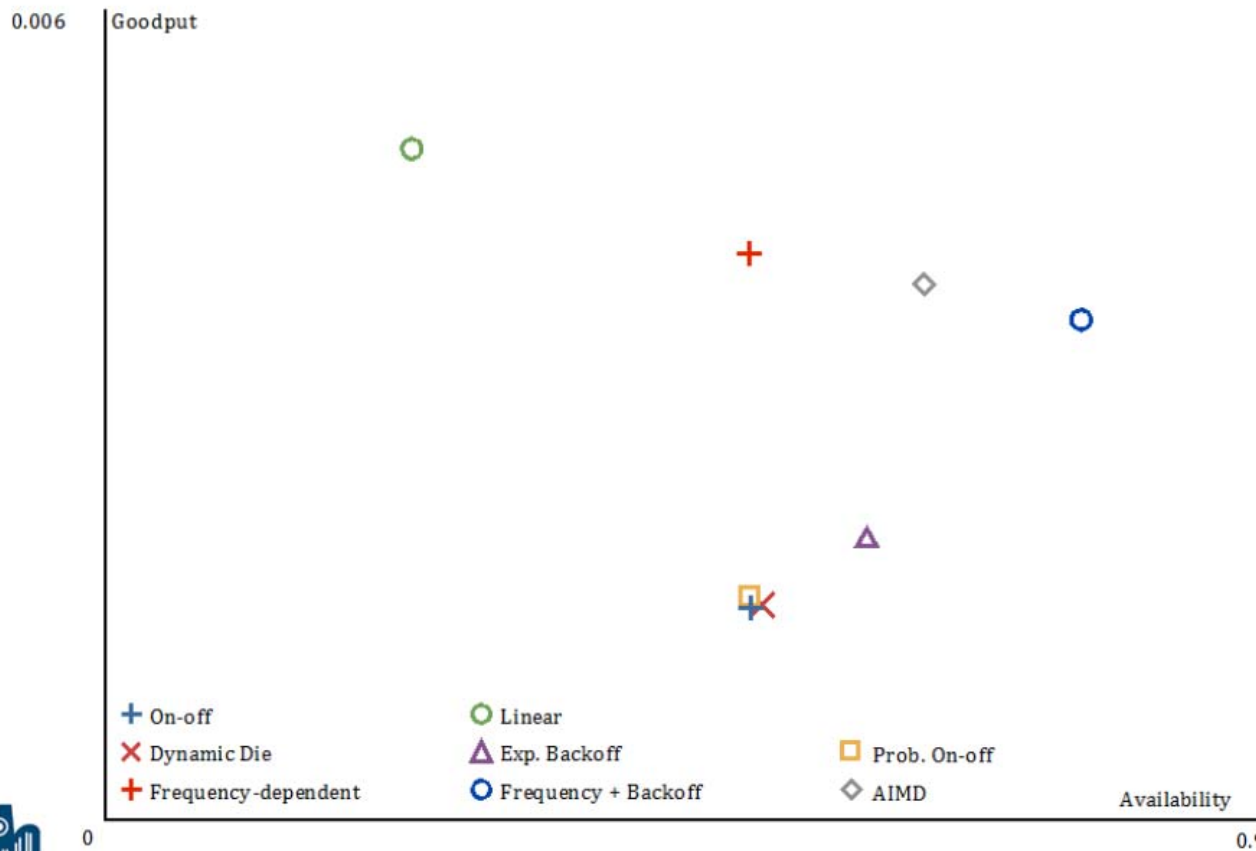


19 Aug 2013

Controller Model Checking Results



Availability vs. goodput

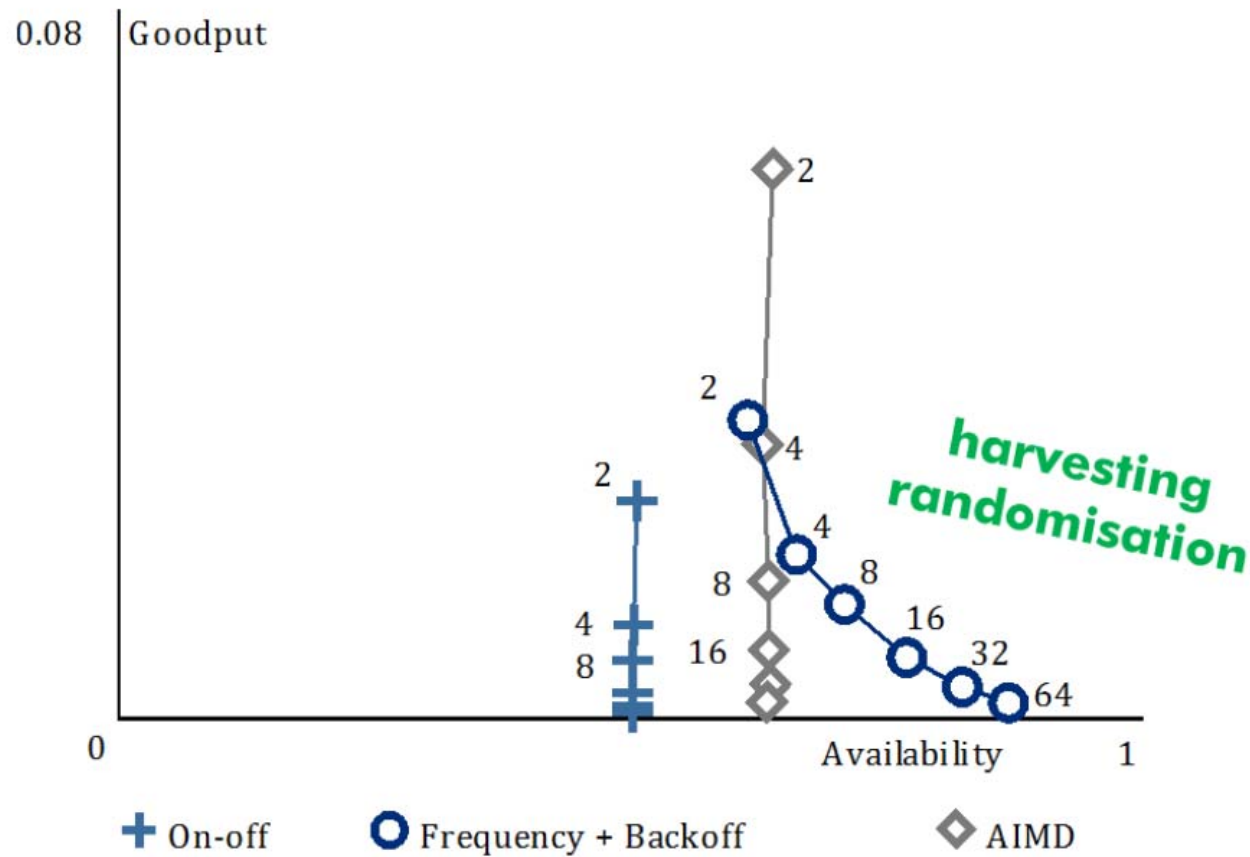


19 Aug 2013

Controller Model Checking Results



Availability vs. goodput



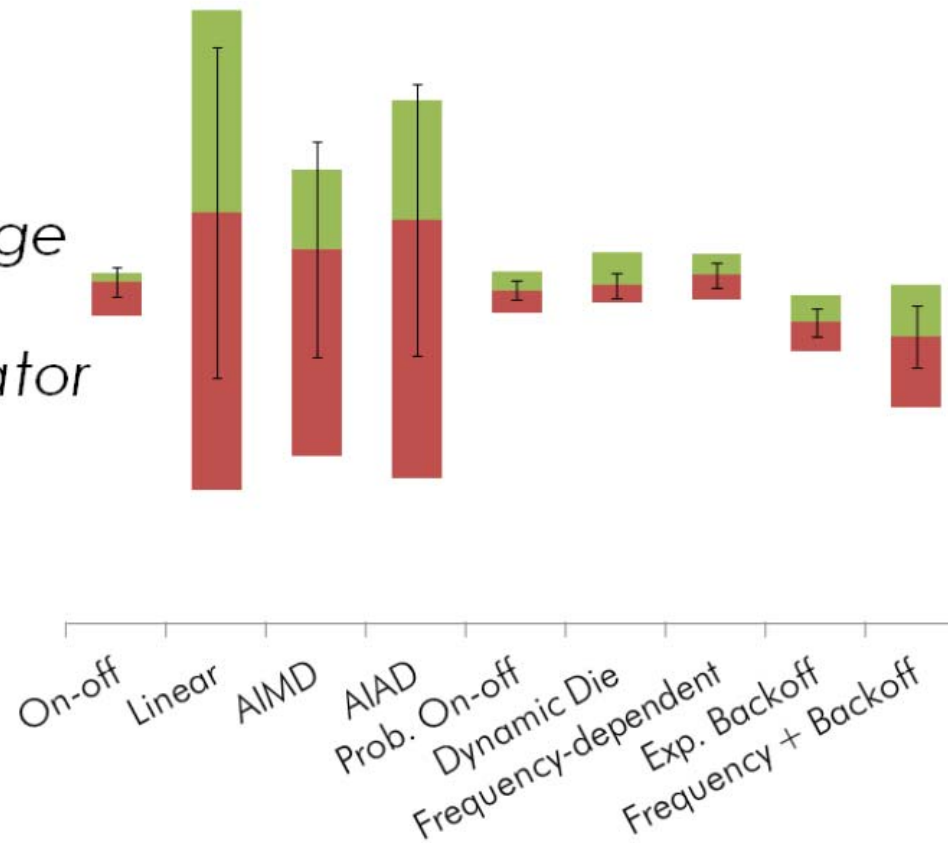
19 Aug 2013

Controller Model Checking Results



Fairness

*max/min/average
output
per generator*



19 Aug 2013

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.

The screenshot shows the mimerp-brp.modest software interface. The main window displays a code editor with a process model for a sender and receiver. The right-hand side contains an analysis panel with configuration options, progress indicators, and a results table.

```
process Sender()
{
  bool bit;
  int(0..MAX) rc;
  clock c;

  do {
    :: invariant(c <= 0) new_file (= 1=0, rc=0 =);
    try {
      do {
        :: when(1 < N) urgent (= 1=1+1 =);
        do {
          :: // send frame
          invariant(c <= 0) put_k (= ff=(1==
          invariant(c <= TS) all {
            :: get_1 (= bit=bit, rc=0, c=0
            // ack received
            urgent break
            :: when(c == TS 66 rc < MAX)
            // timeout, retry
            (= rc=rc+1, c=0 =);
            :: when(c == TS 66 rc == MAX 66
            // timeout, no retries left
            a_nok (= rc=0, c=0 =);
            urgent throw(error)
            :: when(c == TS 66 rc == MAX 66
            // timeout, no retries left
            a_ok (= rc=0, c=0 =);
            urgent throw(error)
          }
        }
      }
    }
    :: when(1 == N)
    // file transmission successfully compl-
    urgent a_ok (= first_file_done=true =);
    urgent break
  }
}
catch error {
  // File transfer did not succeed: wait, then
  invariant(c <= SYNC) when(c == SYNC)
  a_restart (= bit=false, first_file_done=true
}
}

process Receiver()
{
  bool r_ff, r_lf, r_ab;
  bool bit;
}
```

brp.modest (Analysis)

Analysis type: modes: Discrete-event simulation

Experiments: MAX=2 Ns=16 TD=1

Progress

Model Compilation
Experiment 1

Messages

Removing 2 declared but unused symbol(s)
Got 5 processes, 25 variables, 17 action symbols, 4 exception symbols

brp.modest (Results)

Type of analysis: modes: Discrete-event simulation
Analysis options: Runs=2000 RNG=Fibonacci
Completed at: 15.11.2011 17:44:14

Property	Result	Observations	Standard Deviation
T_A2	True	2000	n/a
F_A	0,0000000000000000E+000	2000	0,0000000000000000E+
F_B	0,0000000000000000E+000	2000	0,0000000000000000E+
F_1	5,0000000000000000E-004	2000	2,236067977499790E-
F_2	0,0000000000000000E+000	2000	0,0000000000000000E+
F_3	5,0000000000000000E-004	2000	2,236067977499790E-
F_4	0,0000000000000000E+000	2000	0,0000000000000000E+
Dmax	9,9950000000000001E-001	2000	2,236067977499790E-
Dmin	9,9950000000000001E-001	2000	2,236067977499790E-
Emax	3,3514500000000000E+001	2000	2,157557711311292E+
Emin	3,3514500000000000E+001	2000	2,157557711311292E+



19 Aug 2013

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

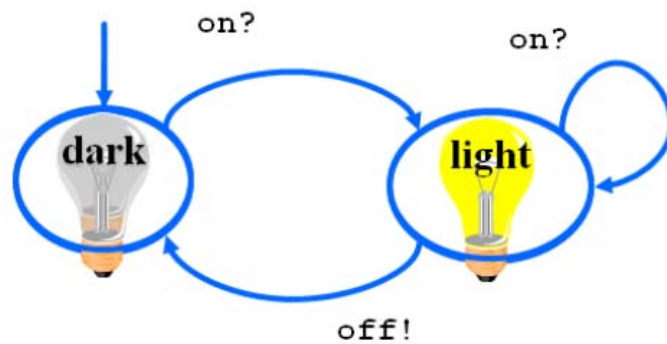
19 Aug 2013



Quantitative Models

A quantitative automata family

Finite Automata



FA

Quantitative Models



A quantitative automata family

Finite Automata

Markov Chains



FA

MC

Quantitative Models

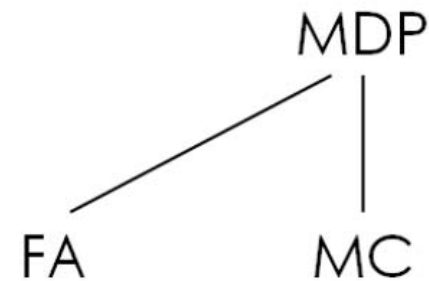
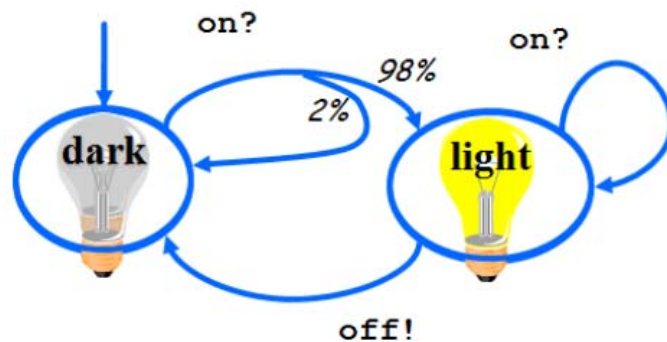


A quantitative automata family

Finite Automata

Markov Chains

Markov Decision Processes



Quantitative Models



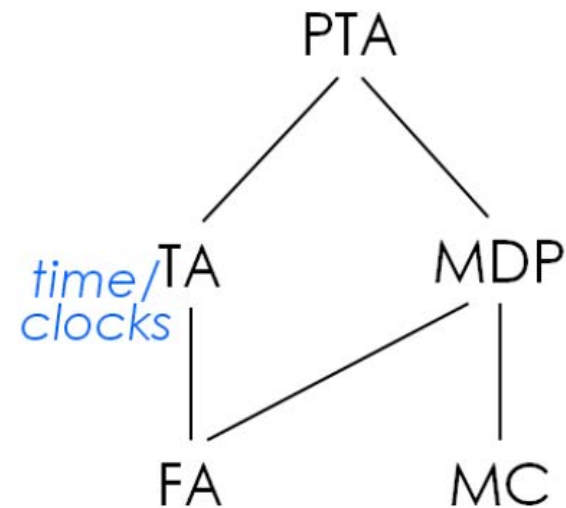
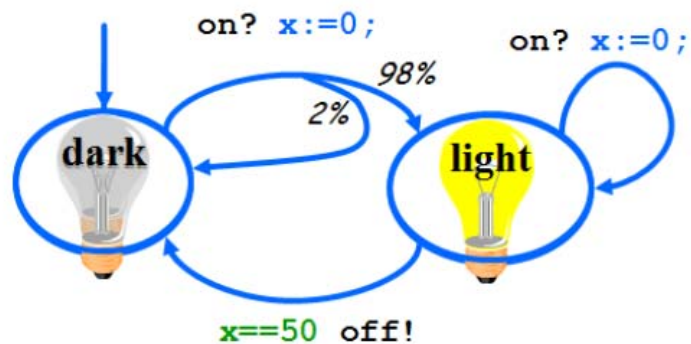
A quantitative automata family

Finite Automata

Markov Chains

Markov Decision Processes

Probabilistic Timed Automata



Quantitative Models and Their Compositions



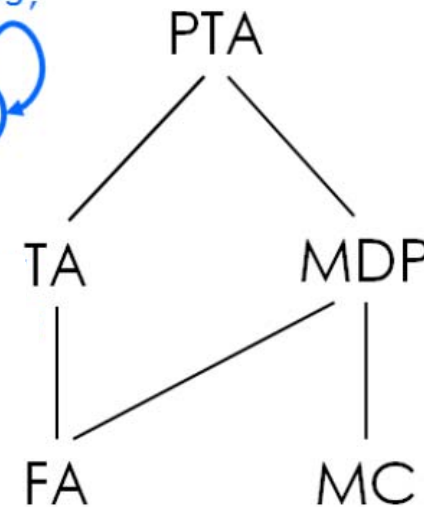
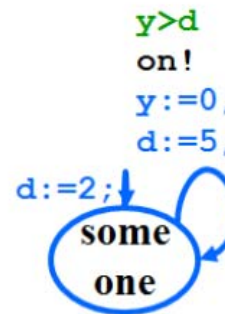
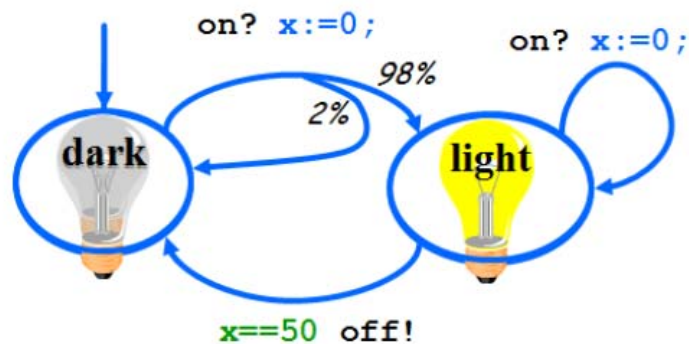
A quantitative automata family

Finite Automata

Markov Chains

Markov Decision Processes

Probabilistic Timed Automata



Quantitative Models and Their Compositions



A quantitative automata family

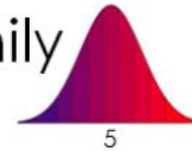
Finite Automata

Markov Chains

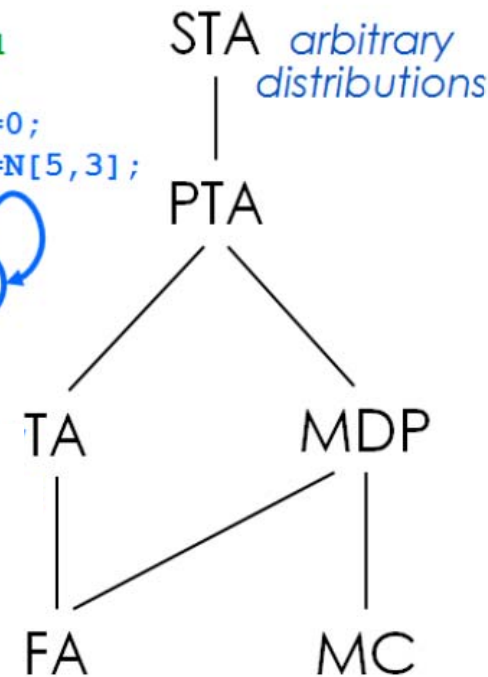
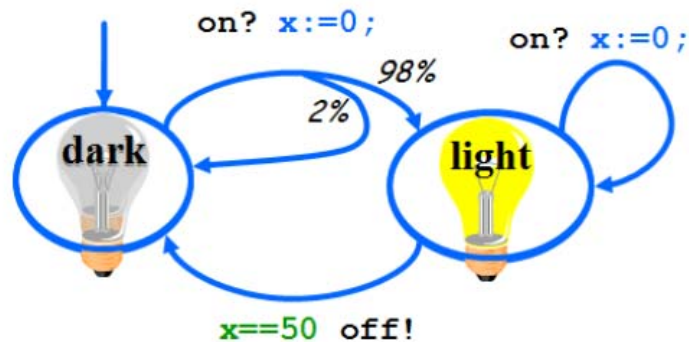
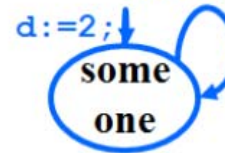
Markov Decision Processes

Probabilistic Timed Automata

Stochastic Timed Automata



$y > d$
 on!
 $y := 0;$
 $d := N[5, 3];$



Quantitative Models and Their Compositions

A quantitative automata family

Finite Automata

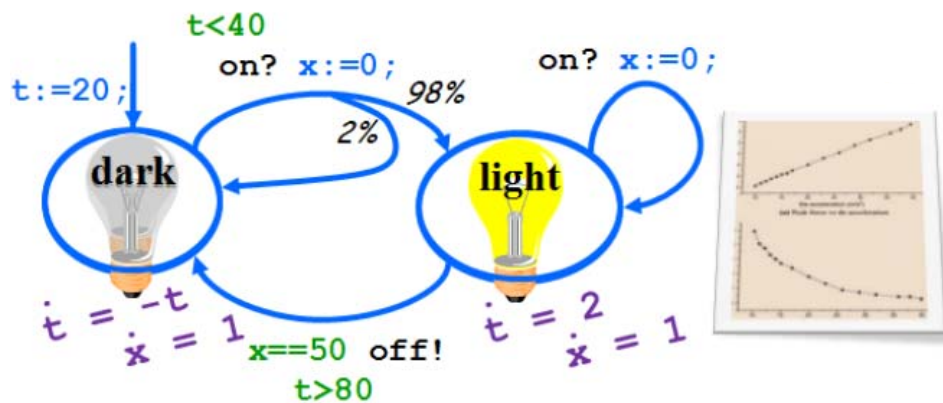
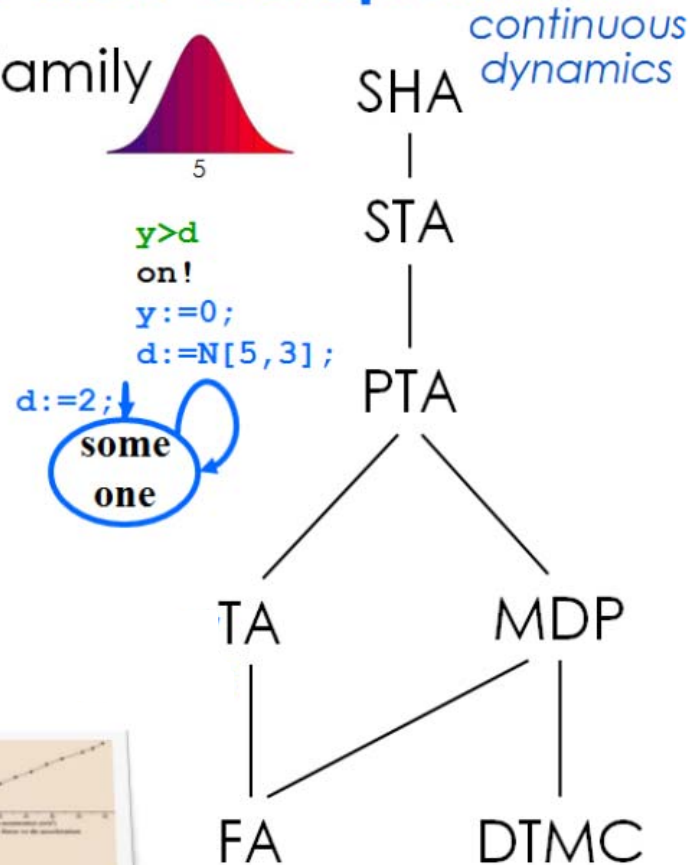
Markov Chains

Markov Decision Processes

Probabilistic Timed Automata

Stochastic Timed Automata

Stochastic Hybrid Automata



The Modest Toolset



mime

GUI

The left screenshot displays the source code for a process named 'Sender' in a probabilistic time-bounded reachability analysis. The code includes comments and properties such as Dmax, Dmin, Emax, and Emin, along with a process definition for 'Sender' that uses a loop to send frames and handle timeouts.

```
// Probabilistic time-bounded reachability pro
// "the maximum/minimum probability that the s
// a successful transmission within 64 time un
property Dmax = Pmax(<> s_ok_seen && time <= 6
property Dmin = Pmin(<> s_ok_seen && time <= 6

// Expected reachability properties
// "the maximum/minimum expected time until th
// of the first file is finished (successfully)
property Emax = Xmax(time | first_file_done);
property Emin = Xmin(time | first_file_done);

process Sender()
{
  bool bit;
  int(0..MAX) rc;
  clock c;

  invariant(c <= 0) new_file {= i=0, rc=0 =};
  try {
    do {
      :: when(i < N) invariant(c <= 0)
      do {
        :: // send frame
        invariant(c <= 0) put
        invariant(c <= TS) all
        :: get_l {= bit=!bit
        // ack received
        invariant(c <= 0)
        :: when(c == TS &&
        // timeout, retu
        {= rc=rc+1, c=0
        :: when(c == TS &&
        // timeout, no r
        s_nok {= rc=0, c=0 =};
        invariant(c <= 0) throw(error)
        :: when(c == TS && rc == MAX && i ==
        // timeout, no retries left
```



The Modest Toolset

mctau – mcpta – prohver – modes – mime – mosta

semantics



four analysis tools

GUI

```
mime
brp.modest x brp.modest – Results brp.modest – Analysis
// Probabilistic time-bounded reachability pro
// "the maximum/minimum probability that the s
// a successful transmission within 64 time un
property Dmax = Fmax(<> s_ok_seen && time <= 6
property Dmin = Fmin(<> s_ok_seen && time <= 6

// Expected reachability properties
// "the maximum/minimum expected time until th
// of the first file is finished (successfully)
property Emax = Xmax(time | first_file_done);
property Emin = Xmin(time | first_file_done);

process Sender()
{
  bool bit;
  int(0..MAX) rc;
  clock c;

  invariant(c <= 0) new_file {= i=0, rc=0 =};
  try {
    do {
      :: when(i < N) invariant(c <= 0)
      do {
        :: // send frame
        invariant(c <= 0) put
        invariant(c <= TS) all
        :: get l {= bit=!bit
        // ack received
        invariant(c <= 0)
        :: when(c == TS &&
        // timeout, retr
        {= rc=rc+1, c=0
        :: when(c == TS &&
        // timeout, no r
        s nok {= rc=0, c=0 =};
        invariant(c <= 0) throw(error)
        :: when(c == TS && rc == MAX && i ==
        // timeout, no retries left
```

```
mime
New Open Save Save As Save All
brp.modest brp.modest – Results brp.modest – Anal
Result: True
Time: 0.0 s
+ Property P_A
Result: 0
Time: 0.0 s
+ Property P_B
Result: 0
Time: 0.0 s
+ Property P_1
Result: 0.000423332873690399
Memory: 0.12 MB
Time: 3.4 s
+ Property P_2
Result: 2.64530799164126E-05
Memory: 0.12 MB
Time: 1.0 s
+ Property P_3
Result: 0.000185191171803529
Memory: 0.12 MB
Time: 2.0 s
+ Property P_4
```



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



Bogdoll, David, Hartmanns, Hermanns: SPIN 2012

19 Aug 2013

**mctau: Bridging the Gap
between Modest and UPPAAL***

Jonathan Bogdoll², Alexandre David¹, Arnd Hartmanns², and Holger Hermanns¹
¹ Aalborg University, Department of Computer Science, Aalborg, Denmark
² Saarland University – Computer Science, Saarbrücken, Germany

* compositional modelling language
- semantics in terms of stochastic
- with several well-known
- like use

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



19 Aug 2013

Hartmanns, Hermanns: QEST 2009

A Modest Approach to Checking Probabilistic Timed Automata

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

	Results	Properties
forward reachability	upper bounds	min. probabilistic reachability
backward reachability [9]	exact	full PCTL
digital clocks [9]	exact	full probabilistic and exact reachability

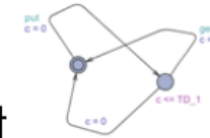
Table 1: CHECKING APPROACH

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

NONDETERMINISM
simulation



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

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

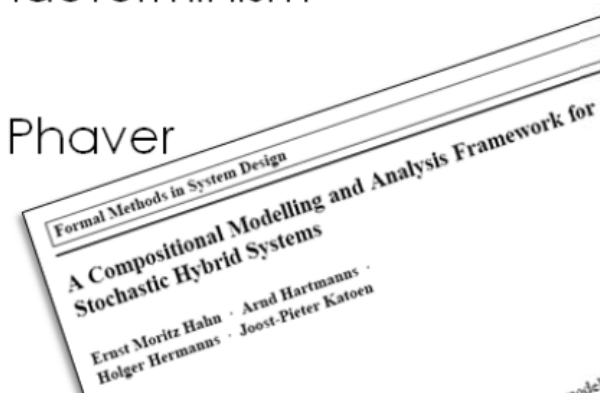
modes Simulation & Statistical Model Checking for STA
with spurious nondeterminism

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



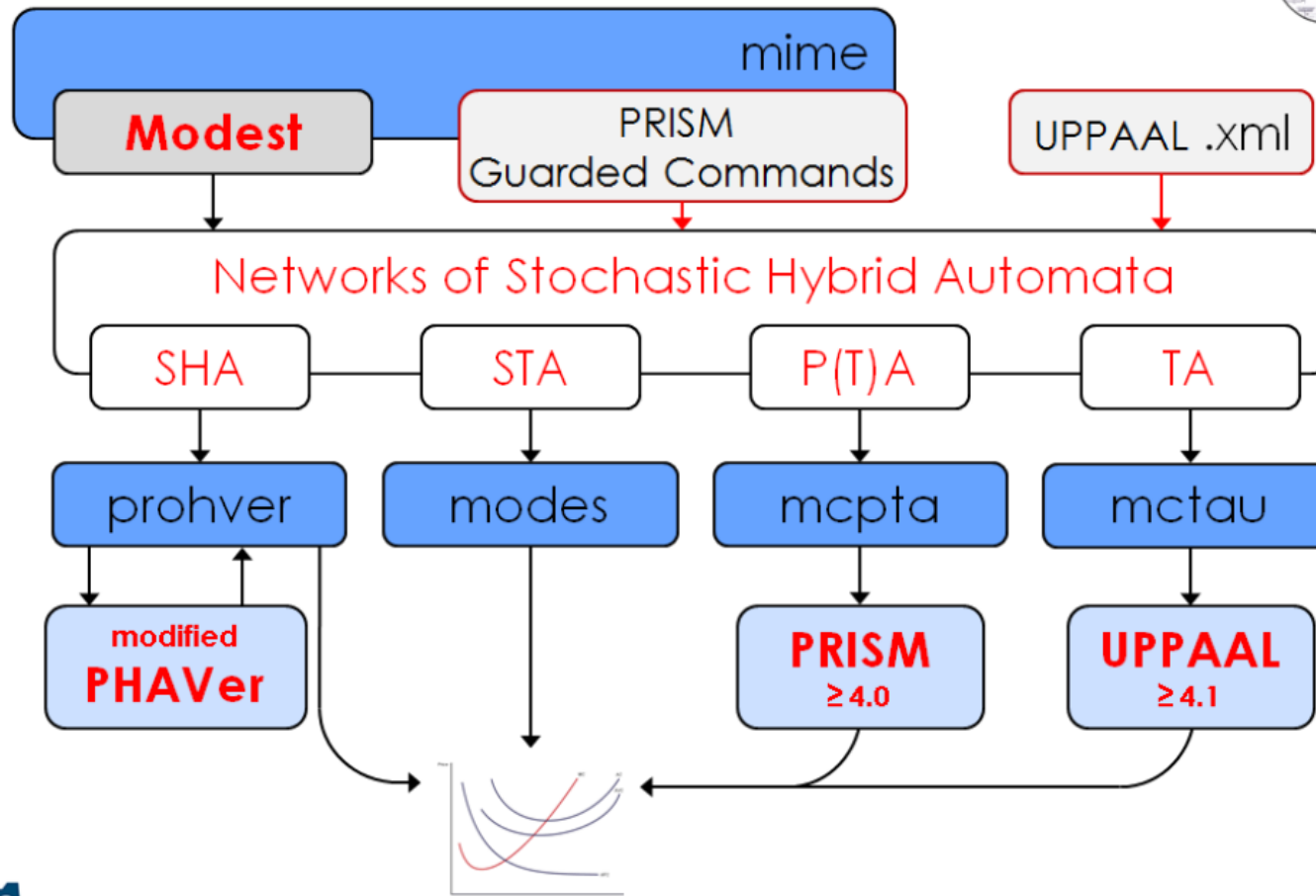
19 Aug 2013

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



model /

The Modest Toolset



Conclusion

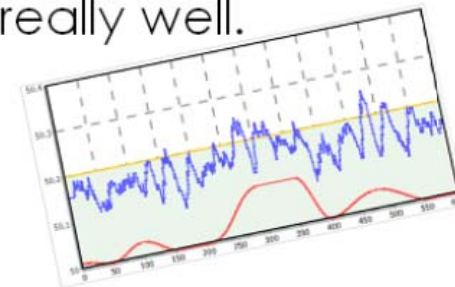


Photovoltaic microgeneration creates new challenges.

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 structures based on distributed microgeneration. As the share of renewable energy sources such as wind and solar power increases, the power production becomes subject to unpredictable fluctuations. This paper reports on the

simulation study

Proceedings of the 2012 Winter Simulation Conference
C. Laroque, J. Hummelshoch, 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 photovoltaic microgeneration. Simulation studies show that the current regulatory framework in Germany can handle such a situation. This phenomenon is indeed recognized by the German Federal Net Code, which is being revised. We compare the national power grids, and new regulations are currently being developed. We compare the national power grids, and new regulations are currently being developed. We compare the national power grids, and new regulations are currently being developed.

← WSC 2012 →
← ISoLA 2012 →