Model Checking LTL properties of High-Level Petri Nets with Fairness Constraints

Timo Latvala*
Helsinki University of Technology,
Laboratory for Theoretical Computer Science,
P.O.Box 9700, 02015 HUT, Finland
http://www.tcs.hut.fi/maria/

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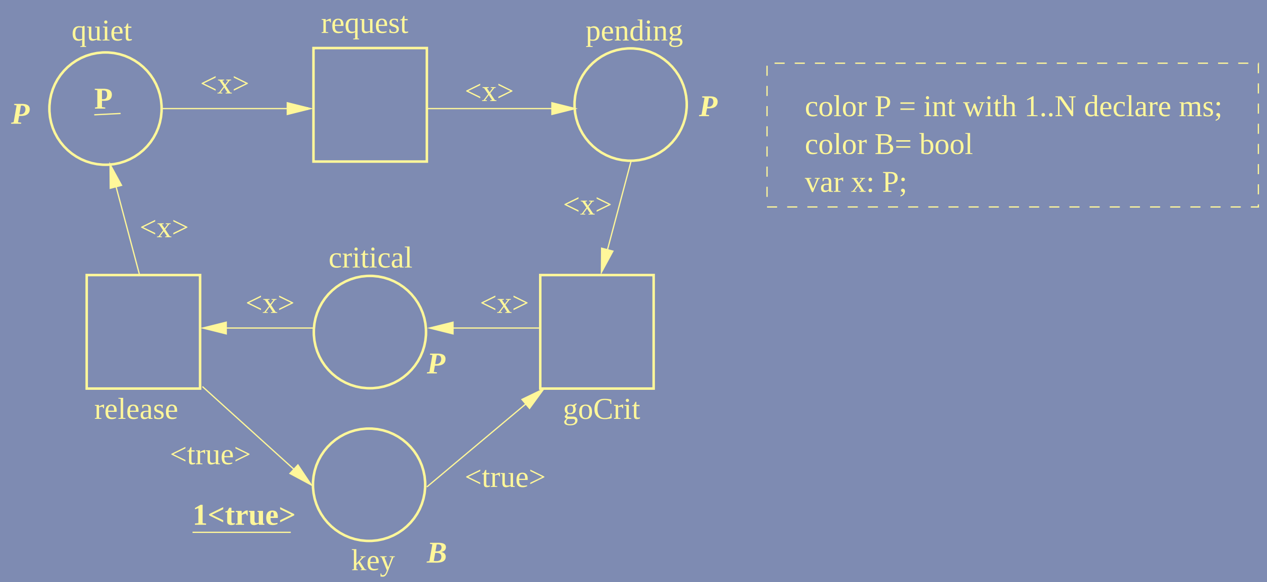
- Why is fairness important?
- The old solution
- A new approach
- Case study: Sliding window protocol
- Conclusions

Why is fairness important? (1/3)

- We usually distinguish between two classes of behavioural properties of distributed systems
  - Safety properties: "Something bad will never happen"
  - Liveness properties: "Something good will eventually happen"
- In many cases *liveness* properties cannot be proven without making some assumptions.
- *Fairness* is considered a reasonable and useful assumption

Why is fairness important? (2/3)

- Weak fairness: if an event is continuously enabled it will occur infinitely often
- Strong fairness: if an event is infinitely often enabled it will occur infinitely often
- Both weak and strong fairness can be expressed in LTL
- Weak fairness: $\Box\Diamond(\neg en \vee oc)$.
- Strong fairness: $\Box\Diamond(en) \Rightarrow \Box\Diamond(oc)$



- Accessibility does not hold if we do not assume that the transition *goCrit* is strongly fair w.r.t. each instance.

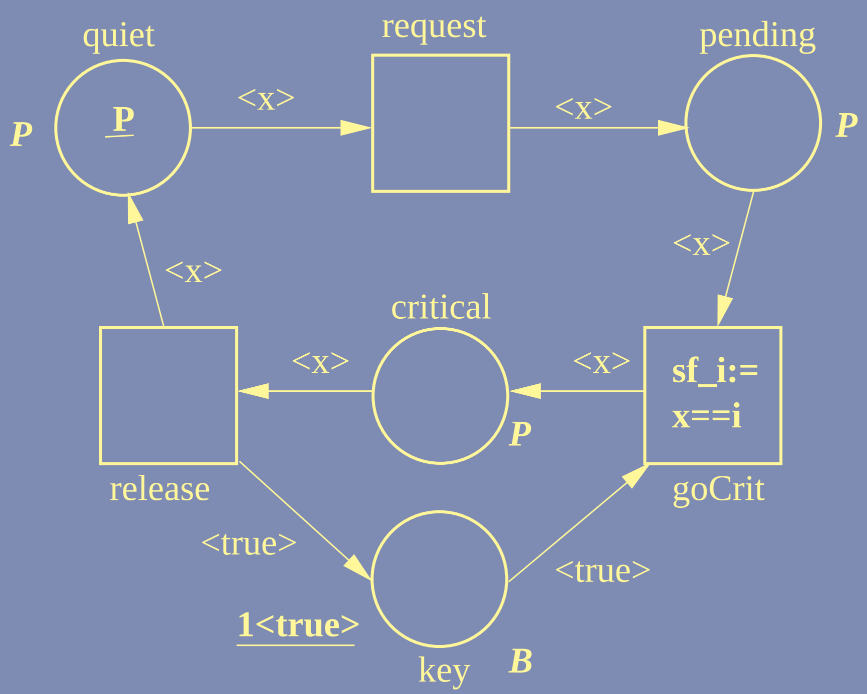
- We remember that fairness can be expressed in LTL
- Thus we verify the formula “$fairness \Rightarrow property$”
- Sometimes an explicit scheduler has to be modelled, in order for this to work.

- Model checking LTL is *PSPACE-complete* in the size of the formula
- May require changes in the model (adding scheduler)
- Adding scheduler can reduce the concurrency in the model, affecting some partial order methods.

A *fair CPN (FCPN)* is a triple $\Sigma_F = \langle \Sigma, WF, SF \rangle$, where Σ is a CPN, and $WF = \{wf_1, \ldots, wf_k\}$ is a set of weak fairness functions, where wf_i is function from transitions to boolean valued expressions. SF is the corresponding set of *strong fairness* functions.

- Fairness is made a part of the model
- The fairness functions singles out the instances which are to be treated fairly.

Example



color P = int with 1..N declare ms;
color B= bool
var x: P;

A **fair Kripke structure (FKS)** is a quintuple $K_F = \langle S, \rho, s_0, \mathcal{W}, \mathcal{S} \rangle$, where S is a set of states, $\rho \subseteq S \times S$ is a transition relation and $s_0 \in S$ is the initial state.

- The fairness requirements are defined by a set of *weak fairness* requirements $\mathcal{W} = \{J_1, J_2, \ldots, J_k\}$ where $J_i \subseteq S$, and a set of *strong fairness* requirements, $\mathcal{S} = \{\langle L_1, U_1 \rangle, \ldots, \langle L_m, U_m \rangle\}$ where $L_i, U_i \subseteq S$.

- An execution is an infinite sequence of states $\sigma = s_0 s_1 s_2 \ldots \in S^\omega$, where s_0 is the initial state, and for all $i \geq 0$, $(s_i, s_{i+1}) \in \rho$.

- Computations, i.e. fair executions of the system, are sequences that obey the fairness requirements $\bigwedge_{i=1}^{k} Inf(\sigma) \cap J_i \neq \emptyset$ and $\bigwedge_{i=1}^{m} (Inf(\sigma) \cap L_i = \emptyset \vee Inf(\sigma) \cap U_i \neq \emptyset)$.

- The constraints of FKS correspond to Generalised Büchi automata and Streett automata acceptance conditions respectively.

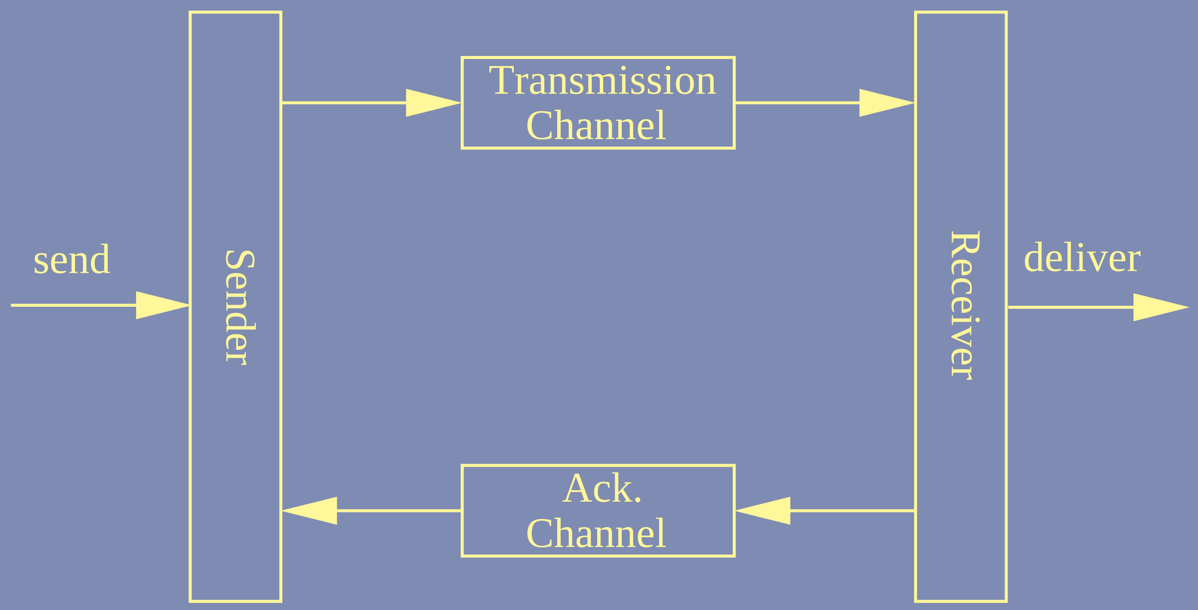
- The new procedure combines emptiness checking for Büchi and Streett acceptance conditions

- We try to avoid using the more time consuming Streett emptiness checking procedure if possible.

- The procedure has been implemented in the Maria tool.

- Emerson and Lei: Fair-CTL model checking
- Knesten, Pnueli and Raviv: Symbolic Fair LTL model checking
- Latvala and Heljanko: LTL model checking for P/T nets with fairness constraints on the transitions.

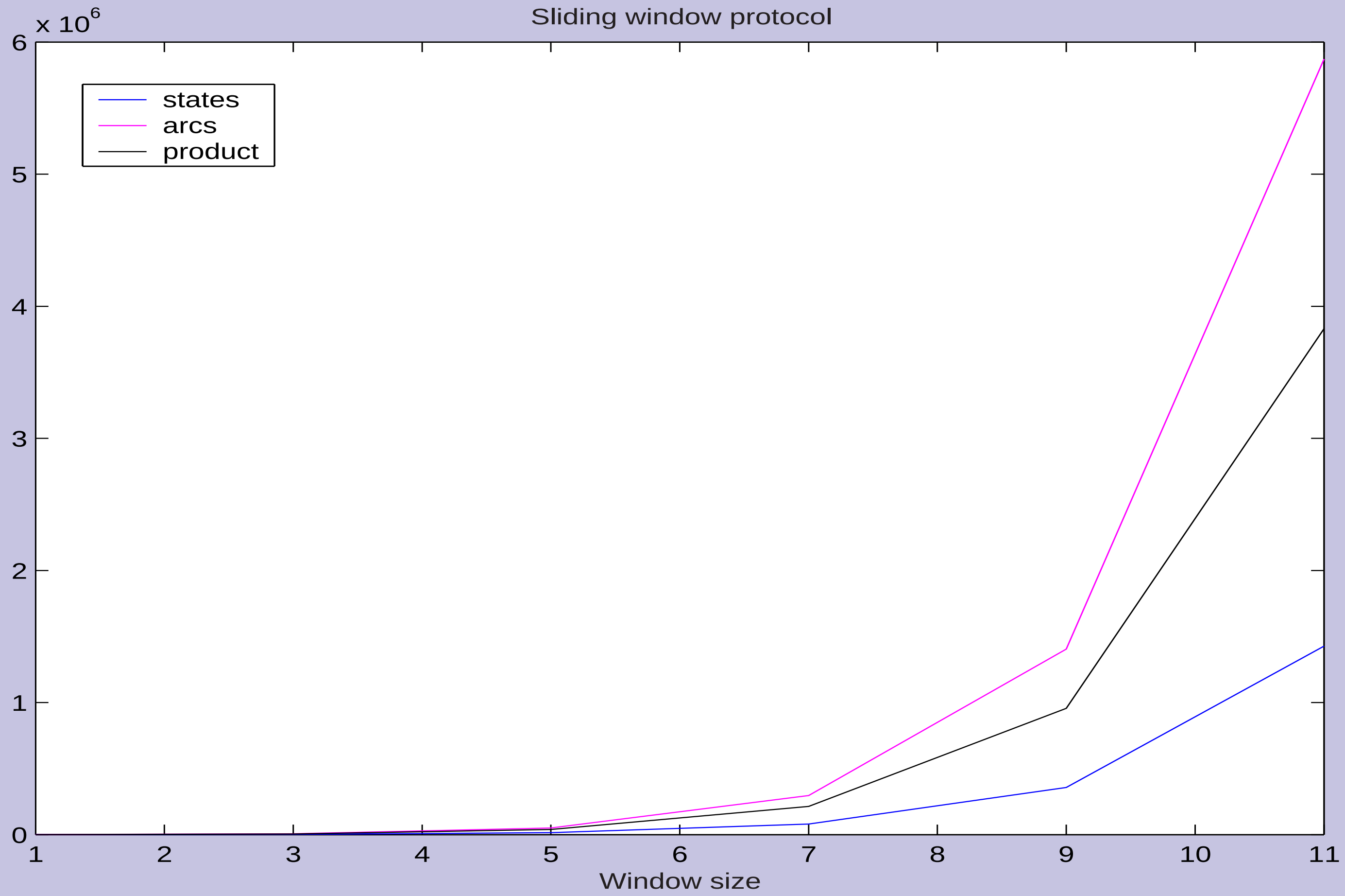
A sliding window protocol



- Provides reliable transmission over an unreliable medium
- This version is due N.V. Stenning
- The model follows closely the model presented by R. Kaivola
- We wish to verify that as many targets should be delivered to the target as are read from the data source. This holds only under a fairness constraint.

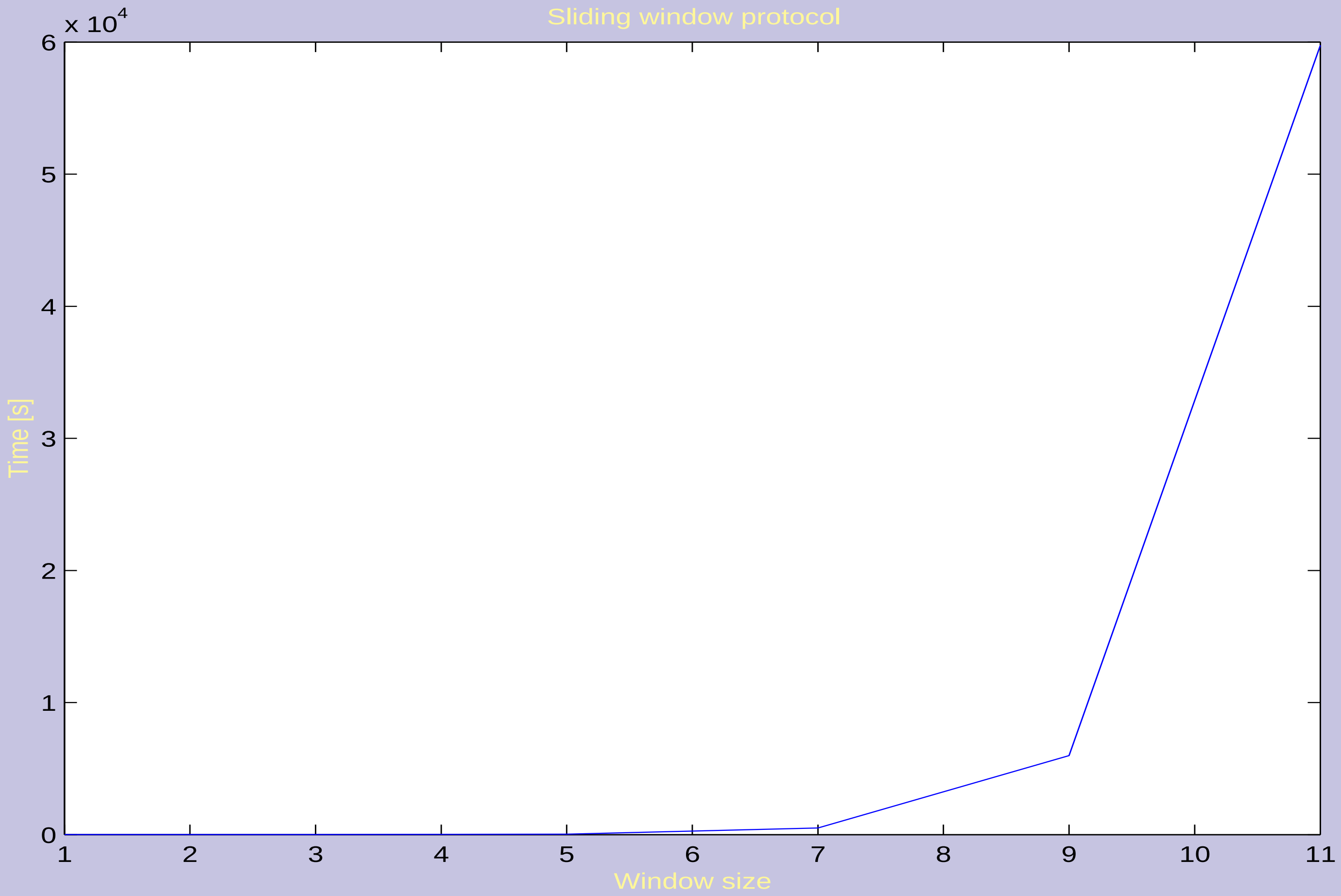
- Using the powerful type system and algebraic operations of Maria, modelling is straightforward.
- Complete model: 12 places and 9 high-level transitions.
- Strong fairness constraints on receive-transitions of the sender and the receiver processes.
- A weak fairness constraint is needed on the receiver side to guarantee progress in the sequential parts.

Results



Sliding window protocol
× 10^6
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
Window size
states
arcs
product

Results



Sliding window protocol
x 10^4
6
5
4
3
2
1
0
Time [s]
1
2
3
4
5
6
7
8
9
10
11
Window size

- We can do LTL model checking on high-level Petri nets with versatile fairness constraints on the transitions
- The procedure is much more efficient than specifying fairness as part of the property to be verified
- The procedure has been implemented in the Maria tool and found to scale fairly well
- Effect on partial order methods?