IEEE 802.11 Wireless LAN

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1 Description of the Model

In this case study we consider model-checking of some properties for IEEE 802.11 Wireless LAN [1]. Since stations in wireless LANs are not able to listen to their own transmission they cannot employ Carrier Sense Multiple Access with Collision Detection (CSMA/CD) as already investigated in one of our other case studies. Hence, other techniques need to be used to handle collisions. The IEEE 802.11 standard describes Carrier Sense Multiple Access with Collision **Avoidance** (CSMA/CA) which is of our main interest in this case study. CSMA/CA also makes use of exponential backoff, but, unlike in CSMA/CD, a randomised exponential backoff rule is used to minimise the likelihood of transmission collisions instead of a "fixed" one. The according *PRISM* case study [3] uses a manually generated model with digital clocks semantics. We reimplement it in Modest [2] in order to compare the performance of the *PRISM* code generated by *mcpta* and that of the hand-written model. The initial setting is rather easy. There are two stations each of which tries to send a message to the other leading to a collision. To obtain the Modest model, we apply a cannonical transformation to the probabilistic timed automaton (PTA) of the *PRISM* case study. States of the PTA are transformed to Modest processes, every non-deterministic choice in a state is translated to an **alt**, state invariants are preserved in an **invariant** construct and every outgoing edge (l, g, a, μ) is transformed to **when**(g) a followed by a probabilistic choice **palt** over the destinations. Clock resets are performed according to μ. The exponential backoff is encoded as an assignment $backoff := DiscreteUniform(0, 2^{bc+4} - 1)$. *Mcpta* generates the according *PRISM* code, 150 lines even for this assignment, fully automatic. We check certain probabilistic reachability, expected-time reachability and probabilistic time-bounded reachability properties for the aforementioned model:

1. **Probabilistic reachability properties:**

   (a) $P_{\geq 1}$: with probability 1, eventually both stations have sent their packet correctly
   $P(\Diamond\ did(success_1)\ \&\&\ did(success_2)) \geq 1.0$

(b) P_{max} : the maximum probability that either station's backoff counter reaches K
$P_{max}(\Diamond\ did(bck_1)\ ||\ did(bck_2))$

2. **Expected-time reachability properties:**

   (a) $E_\wedge$: the maximum expected time until both stations correctly deliver their packets
   $T_{max}(did(success_1)\ \&\&\ did(success_2))$

   (b) $E_\vee$: the maximum expected time until either station correctly delivers its packet
   $T_{max}(did(success_1)\ ||\ did(success_2))$

   (c) E_1 : the maximum expected time until station 1 correctly delivers its packet
   $T_{max}(did(success_1))$

3. **Probabilistic time-bounded reachability properties:**

   (a) $D_\wedge$: the minimum probability of both stations correctly delivering their packets within time *DEADLINE*
   $P_{min}(\Diamond\ did(success_1)\ \&\&\ did(success_2)\ \&\&\ time \leq DEADLINE)$

   (b) $D_\vee$: the minimum probability of either station correctly delivering its packet within time *DEADLINE*
   $P_{min}(\Diamond\ did(success_1)\ ||\ did(success_2)\ \&\&\ time \leq DEADLINE)$

   (c) D_1 : the minimum probability of station 1 correctly delivering its packet within time *DEADLINE*
   $P_{min}(\Diamond\ did(success_1)\ \&\&\ time \leq DEADLINE)$

2 Results

We checked the properties for two different configurations (BCMAX,TTMAX) where BCMAX is the maximal backoff and TTMAX is a scaling factor. We used configuration (2,315) for the probabilistic reachability properties and (2,25) for both expected-time and probabilistic time-bounded reachability. The model-checking results are listed in Table 1. We obtained the same results from the Modest model and the model from the *PRISM* case study. The state-spaces of the underlying MDPs of both the hand-written and automatically generated model is compared in Table 2. As can be seen, the MDP of the automatically generated model consists only of 33% of the states needed for the hand-written one. In fact, smaller MDPs do not necesserily lead to better performance measures since a larger model might have a better structure that allows fast model-checking. However, in this case our model lead to faster model-checking (including the model construction time "MC") even it's only in the order of seconds. Additionally, our model safes at least 50% up to about 80% memory. The performance results are given in Table 3. They were obtained on an Intel Core Duo T9300 (2.5 GHz) system.

	K=BCMAX=2, TTMAX = 315, no deadline	K=BCMAX=2, TTMAX=25, DEADLINE=5000μs
$P_{\geq 1}$	true	true
P_{max}	0.184	0.184
$E_{\wedge}$	n/a	6280 μs
$E_{\vee}$	n/a	4206 μs
E_1	n/a	5586 μs
$D_{\wedge}$	n/a	0.000
$D_{\vee}$	n/a	0.816
D_1	n/a	0.132

Table 1: Results of model-checking for the considered properties

	Modest	*PRISM*
Standard	116280	447872
Expected	31026	170632
Deadlines	1850590	5227058

Table 2: Comparison of the state-space size of both models

	Modest		*PRISM*	
MC	7s	-	16s	-
$P_{\geq 1}$	23s	n/a	30s	n/a
P_{max}	5s	2969 kB	6s	11025 kB
MC	1s	-	1s	-
$E_{\wedge}$	5s	2457 kB	9s	11973 kB
$E_{\vee}$	3s	2355 kB	7s	11754 kB
E_1	4s	2457 kB	8s	11863 kB
MC	14s	-	26s	-
$D_{\wedge}$	24s	46080 kB	19s	128202 kB
$D_{\vee}$	19s	62259 kB	24s	135559 kB
D_1	23s	56832 kB	26s	132994 kB

Table 3: Comparison of model-checking time and memory consumption for Modest and *PRISM*

References

[1] Arnd Hartmanns. A Modest Checker for Probabilistic Timed Automata. Reports of SFB/TR 14 AVACS 49, SFB/TR 14 AVACS, April 2009. ISSN: 1860-9821.

[2] Arnd Hartmanns and Holger Hermanns. A Modest Approach to Checking Probabilistic Timed Automata. In *QEST*. IEEE Computer Society, September 2009.

[3] M. Kwiatkowska, G. Norman, and J. Sproston. Probabilistic Model Checking of the IEEE 802.11 Wireless Local Area Network Protocol. In H. Hermanns and R. Segala, editors, *Proc. 2nd Joint International Workshop on Process Algebra and Probabilistic Methods, Performance Modeling and Verification (PAPM/PROBMIV'02)*, volume 2399 of *LNCS*, pages 169–187. Springer, 2002.