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Formal Verification of Collision Free Mobility Adaptive Protocol for Wireless Sensor Networks

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***Abstract*—There has been a rapid growth in the need to support mobile nodes in Wireless Sensor Networks (WSNs). This may lead to several uncertainties and stochastic events such as messages loss, collisions on medium and even loss of nodes. Therefore, it is essential to ensure the efficiency of mobility based wireless sensor protocols. A lot of protocols have been proposed to consider mobility in the MAC layer as well as in the network layer. We opt to study formally one of these protocols using Statistical Model Checking (SMC). The chosen protocol is CFMA (Collision Free Mobility Adaptive) MAC protocol, for WSNs. This protocol performs well in both static and mobile scenarios. In this paper, we make a formal study for its principal algorithms by modeling, first, its work-flow using probabilistic timed automata. This stochastic formalism leads to consider several random events with more realism. Furthermore, a performance analysis is performed by verifying the qualitative and quantitative properties of this protocol using UPPAAL SMC tool.**

Keywords—WSN; CFMA MAC protocol; Statistical Model Checking; UPPAAL SMC.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) [2] consist of a large number of autonomous and battery-powered wireless devices (nodes). These nodes measure event from the environment where they are deployed then they process and transmit data to a central node in the network called "sink". WSNs have a vast application range including military application, environment monitoring, health-care, smart home, etc. A WSN is usually deployed with static nodes to monitor missions in the interested range. This method could not face many problems due to the dynamic changes of events and the hostile environment. In these scenarios, mobility in WSN can overcome these challenges. It can also cope with one of the main goals in the WSNs design process which is the overall power consumption. formatter will need to create these components, incorporating the applicable criteria that follow.

Collision Free Mobility Adaptive (CFMA) MAC protocol [14] is one of mobility based wireless sensor networks protocols. This protocol has been proposed to guarantee the collision free access in MAC layer. CFMA/MAC performs well in both static and mobile scenarios. It is expected to reduce the power consumption of sensors by ensuring that transmissions incur no collisions and obliges nodes to sleep whenever there is no transmission and reception. Indeed, this protocol uses long periods of inactivity of devices, known as sleep modes. Basically, this protocol reposes on IEEE 802.15.4 Wireless Personal Area Network (WPAN). The IEEE 802.15.4 is well suited to the needs of wireless sensor networks in terms of low throughput, short transmission distance and low energy consumption. With IEEE 802.15.4, each WPAN has one coordinator as a central controller to organize the other components of WPAN. The topologies required by this standard are: (i) peer to peer, (ii) star, (iii) cluster tree. There are two operation modes of the MAC layer depending on the topology used and the need for guaranteed throughput: (i) non-beacon enabled mode, (ii) beacon enabled mode. In beacon mode, beacons are sent in regular period to synchronize devices. In fact, The CFMA/MAC protocol is based on the cluster tree topology and beacon enabled mode. In order to design, simulate and verify communication protocols many researchers have used formal methods such as in [21], [7], [5], [15], [9], [11], [12], [24], [26], [3], [17].

In this paper, our aim is to make a formal study of the CFMA/MAC protocol by illustrating the modeling approach and the automatic verification. In order to model the protocol, we use probabilistic timed automata. We opt to use UPPAAL SMC (Statistical model-checking implemented in UPPAAL) for the performance analysis.

The reminder of this paper is organized as follows. Section II presents the related work overview. The UPPAAL SMC, probabilistic timed automata and the query language used in the UPPAAL SMC are presented in Section III. Section IV elaborates the modeling and the verification of the studied protocol. Finally, Section V concludes this paper.

II. RELATED WORK

The formal verification has been used in networking domain to verify communication protocols in both levels: network layer such as in [21], [7], [5] and MAC layer such as [15], [9], [11], [12], [24], [26], [3], [17]. In [15], the authors proposed protocols dedicated to WSNs using Model Driven Software Engineering (MDSE). They used CPN-tool (coloured Petri Nets) [13] to perform the formal study. The authors in [9] proposed an extension of CSMA/CA where the Distributed Coordination Function (DCF) mode was introduced. They used UPPAAL tool for the formal modeling with the timed automata and a qualitative verification of some

properties was accomplished. The latter work [9] was extended by [11] where the quantitative verification of the aforementioned protocol was considered. In [11], the authors used UPPAAL SMC tool for making a performance analysis using the statistical model checking. In the work reported in [12], the authors studied the protocol IEEE802.11 CSMA/CA using Markov chain. Likewise, the aforementioned protocol was also studied in [24] where the authors used also Markov chain to model the exponential backoff process. On another hand, the authors in [18] took a sub-protocol of the standard IEEE 802.11 called two-way handshake and use both the UPPAAL and PRISM tools for the qualitative and quantitative verifications, respectively. Another WSNs protocol was studied in [26] which is Timing-sync protocol [8] where the authors used stochastic timed automata for the modeling and UPPAAL tool for the verification of qualitative properties. A comparative study was made in [3] between IEEE 802.11 protocol for wireless ad-hoc and S-MAC (Sensor-MAC) using PRISM and PCTL (Probabilistic Computation Tree Logic) to define the properties. The same formalisms were used in [17] to study Distributed Coordination Function (DCF) protocol for automatically verify specific properties.

All the aforementioned works used formal methods in the case of static nodes. Indeed, few works investigated the formal study of mobile nodes in WSNs. The majority of these works used extensive simulation for their performance evaluation in their studies as reported in ([19], [23], [10], [20]). Among the few works tackling the formal study of mobile based WSNs protocols, the two works reported in [4] and [25]. In [4], the authors presented a formal approach for the specification, verification and simulation of wireless sensor network with mobile nodes using Prototype Verification System (PVS) tool. The formal study of the mobility was also addressed in [25] where the authors proposed an approach for the formal modeling and verification of ad-hoc wireless network using stochastic Petri nets.

The contribution of this original paper is the application of formal methods which is represented in the utilization of UPPAAL SMC and Probabilistic Timed Automata (PTAs) for the specification, verification and evaluation of the Collision Free Mobility Adaptive (CFMA) MAC protocol [14] dedicated to WSNs with mobile nodes. At the best of our knowledge, this paper provide the first formal study of the CFMA protocol.

III. Statistical Model Checking (SMC)

The Statistical Model-Checking (SMC) [22] is an extension of the classical model-checking based on stochastic simulation. This extension has been proposed in order to express the probabilistic aspect indispensable for the performance evaluation of some systems. The SMC is an automatic verification approach of quantitative properties with probabilistic aspect. As the classical model-checking, a model-checker SMC takes, on the one hand, a model that describes the behavior of a system, and on the other hand, a formula that specifies the properties to be verified in the system. Then, the SMC generates a number of simulations (runs) randomly and exploits algorithms to make decisions on the validity or the nonvalidity of the verified properties in a probabilistic way.

UPPAAL SMC [6] is based on the classical model checking version of UPPAAL with a consideration of the stochastic characteristics using Probabilistic Timed Automata (PTAs). Likewise, UPPAAL SMC uses a a probabilistic temporal logic language as a query language to specify the properties. The following subsections will present the probabilistic timed automata and the query language used in UPPAAL SMC.

A. *Probabilistic Timed Automata (PTAs)*

Probabilistic Timed Automata (PTAs) [16] are considered as a modeling formalism dedicated for the systems where their behaviors have the probabilistic, real-time and non-deterministic characteristics. Formally, a probabilistic timed automaton is a tuple (L, l, χ, Σ, *inv*, *prob*), where:

- L: A finite set of localities (or states) and $l \subseteq L$;
- χ: A set of variables (called clocks). $\chi \in T$ and $T \in R, N$;
- Σ: A set of events;
- *inv*: $L \rightarrow Zone\{\chi\}$ A function which associates to each locality an invariant; $Zone\{\chi\}$: is the set of logical expressions (guards) in the form: $x \sim c$, such that $x \in \chi$, $\sim \in \{\leq, =, \geq\}$ and $c \in N$;
- *prob*: A finite set of probabilistic transitions: $prob \subseteq L \times Zone(\chi) \times \Sigma \times Dist(2^{\chi} \times L)$. $Dist(2^{\chi} \times L)$ is the set of probabilistic distributions on all countable subsets of the product: $2^{\chi} \times L$. In other words, Each transition links a locality to another locality, and this transition is labelled by: an event, a guard, a set of variables to be reset, and finally a probabilistic transition. So a probabilistic transition is a tuple (l, g, σ, p) such that p is a probability function $p = \mu(X, l')$ defined for each pair $(X, l') \in 2^{\chi} \times L$; with $X \subseteq \chi$.

B. *Query Language*

UPPAAL SMC uses the same query language defined in the standard model checking for the specification of the properties such as: A<> φ, A[] not deadlock and E <> φ (where φ is an expression) for specifying, respectively, the liveness, the safety and the reachability properties. Furthermore, New queries related to the stochastic interpretation of probabilistic timed automata are available in UPPAAL SMC such as:

- *Simulate N* [<= *bound*]*E1, ..., Ek* , where *N* is the number of simulations, *bound* is the time bound on the simulations and *E1, ..., Ek* are expressions of k states to be visualized;
- Pr[<= *bound*](<> φ), where *Pr* denotes the probability to be estimated, *bound* is the time bound and φ denotes an expression.

IV. Formal Modeling and Verification of CFMA/MAC Protocol

The main idea of CFMA/MAC protocol is the allocation of different backoff delays to the nodes. The successful transmission of a frame is informally described as follows:

- In the association phase, the nodes send their priorities to the coordinator. The latter allocates the backoff delays according to its backoff values table. The node which has the high data priority will have the shortest delay with the exception of the mobile nodes which always have the highest priorities. If a mobile node receives a signal from another coordinator, it requests the delay from the adjacent cluster coordinator via the current coordinator. Then, wait timers are introduced to avoid collision;
- In the running phase, the node with data (i.e., in its buffer) to be transmitted, must enter a backoff period before transmitting this data. Then, it sends Request to Send (RTS) signal and initializes the response timer to transmit data. Finally, An acknowledgement of the frame is sent from the coordinator with new values of backoff delays.

In order to facilitate the construction of the formal model, a semi formal modeling based on the Unified Modeling Language (UML)[1] is performed. This semi formal modeling is presented as a sequence diagrams. These latter diagrams show clearly the interactions between the nodes and their coordinator. Fig. 1 shows one of the sequence diagrams that we have made. This diagram depicts the main functionalities of the protocol in the running phase where it illustrates the necessary interactions for the transmission of a frame as described above.

A. *Formal Modeling using PTAs*

This section presents the formal modeling of the CFMA/MAC protocol using Probabilistic Timed Automata (PTAs). The modeling concerns the behaviors of the five entities: the node (static or mobile) in the association phase, the static node in the execution phase, the mobile node in the execution phase, the coordinator and the medium. Due to the limited number of pages, we present only the three models of the mobile node, the coordinator and the medium that we consider the most relevant for the CFMA/MAC protocol. UPPAAL SMC allows to define the probability laws on the locality or the transitions. In the probabilistic models shown in Fig 2 and Fig 3, we associate a rate = 1 for any locality without invariant. Fig 4 shows the probabilistic model of the medium after the use of probabilities on transitions. We associate a probability of 1/10 for each transition leading to a synchronous fail action. A probability of 9/10 is associated for each transition leading to a transmission of a frame. These rates can be updated to show the response of the protocol for several values. In practice, such rates must be identified from

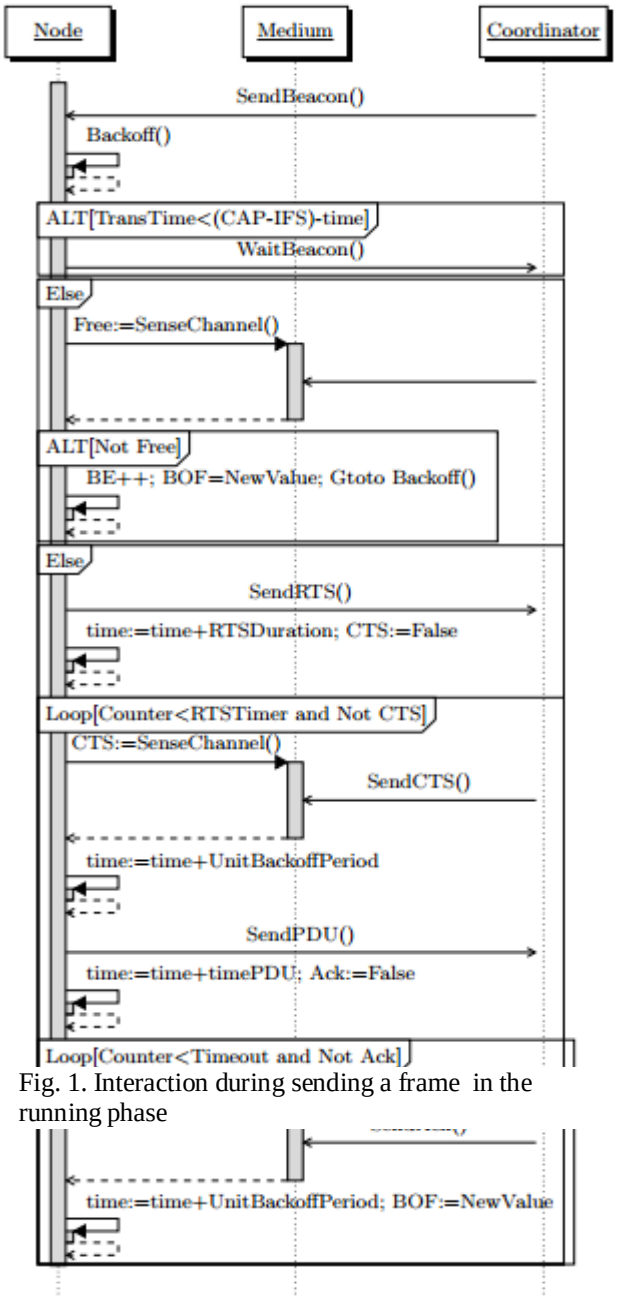

Fig. 1. Interaction during sending a frame in the running phase

statistics and experiments related to the nodes characteristics and the environment where these nodes are deployed.

1) Mobile node model in the running phase:

Once the node nd enters the running phase as depicted in Fig. 2, it performs its backoff delay. Then, it tries to transmit its first frame Protocol Data Unit (PDU) by sending, respectively, (BeginSendRTS, EndSendRTS) and (BeginSendPDU, EndSendPDU). After sending an RTS, the node receives a CTS which is represented by (BeginReceiveCTS, EndReceiveCTS) and after sending a PDU the node receives an acknowledgement (BeginReceiveAck, EndReceiveAck). A mobile node follows the same behavior as a static node, except that it can migrate and change its coordinator when it detects the signal strength of another coordinator. The mobility of a node is represented

by the Moving locality. When it leaves this locality, it makes a change of coordinates after each reception of a beacon. The strength of the signal is modeled by the calculation, on the part of the medium, of the Euclidean distance between the node and the coordinators.

2) Coordinator model:

The Contention Access Period CAP is the period of activity of the coordinator. A coordinator co must listen to the medium during the CAP, if it receives an RTS or a PDU it must send, respectively, (BeginSendCTS, EndSendCTS) or (BeginSendAck, EndSendAck). If the coordinator receives the identity of the adjacent coordinator in the request sent by a mobile node then it sends SendPrio [co] to the adjacent coordinator in order to associate the requesting mobile node with this latter coordinater. Fig. 3 shows the model of the coordinator.

3) Medium model:

The model of the medium seems complicated (as seen in Fig. 4) due to the number of synchronous actions between a coordinator and a node for this reason, we opt to show a part the medium model . After receiving a BeginSend synchronous action, the medium state will be occupied by changing a boolean: M free = false then it sends a BeginReceive or fail action. The same idea is done when it receives an EndSend, where it sends an EndReceive with M_free = true. When the medium receives Send SS with the coordinates of a mobile node, it calculates the distance between the coordinates of this node and the coordinates of the set of coordinators, and then it sends the identity of the new coordinator, which has the smallest distance, to the mobile node.

B. *Qualitative Verification*

We opt to verify some properties before the assignment of the probabilities to the localities and the transitions. Among the main classes of properties that can be expressed in temporal logics, we have studied the following properties using the query language provided in UPPAAL:

- Liveness property: a liveness property allows to express that a state or an event will necessarily occur in the future. we examine whether the node nd_assoc0 will never receive its acknowledgement.
- Safety property: this property is of the form: some bad thing will never happen. For example, whether a deadlock must never occur in the model.
- Reachability property: we examine whether a node can finish the reception of its acknowledgement by the formula: E<>nd assoc0.End Receiving Ack. We also exmine whether a mobile node can receive its acknowledgement.

In our case, we added a clock C to both node models (in association and running phases) to verify whether the nodes nd assoc0 and nd rp0 can reach the state "end of reception of an acknowledgement" before that the clock C reaches a threshold T=1000 and whether a node nd assoc0 occurs a collision before a threshold T lower or equal to 80. The verification results of the aforementioned properties are depicted in Table I.

Tabble I.

Property	Query	Satisfaction
Reachability 1	E<>nd_assoc0.End_Receiving_Ack	Satisfied
Reachability 2	E<>nd_rp0.End_Receiving_Ack	Satisfied
WithT= 1000	E<>(nd_rp0.End_Receving_Ack and nd_rp0.C<= 1000)	Satisfied
With T= 80	E<>(nd_assoc0.may_be_collision and nd_assoc0.C<= 80)	Satisfied
Liveness	A<>nd_assoc0.End_Receiving_Ack	Satisfied
Safety	A [] not deadlock	Undecidable

Discussion: The undecidability of some properties, such as the undecidable property dipected in TABLE I, is due to the state space explosion where the classical model checker of UPPAAL can not handle such a problem. The statistical model checker of UPPAAL SMC and the probabilistic timed automata solve this problem. After making the models probabilistic, we opt to perform a quantitative verification which is presented in the following subsection.

C. *Quantitative Verification*

After the assignment of the probabilities for the localities and the transitions and making the models probabilistic. We can estimate the satisfaction rate (as seen in TABLE II) of each property by making the following queries: (1) Pr[<=100](<> ndassoc0.End_Receiving _Ack): this query examines whether a node can reach the state of End_Receiving_Ack, (2) We also examine whether a node can terminate its association (i.e., it can reach the state End_association), (3) the query Pr[<= 100](<> mnd_rp0.End_Receiving_Ack) examines whether a mobile node can receive an acknowledgement.

TABLE II.

Query	Probability interval	Confidence rate
Pr[<= 100](<> ndassoc0.End_Receiving_Ack)	[0.811702, 0.911483]	0.95
Pr[<= 100000](<> nd_assoc0.End_association)	[0.902606,1]	0.95
Pr[<= 100](<> mnd_rp0.End_Receiving_Ack)	[0.214981,0.314847]	0.95

UPPAAL SMC provides the possibility to draw the characteristic function of probability and hereafter some results with discussions.

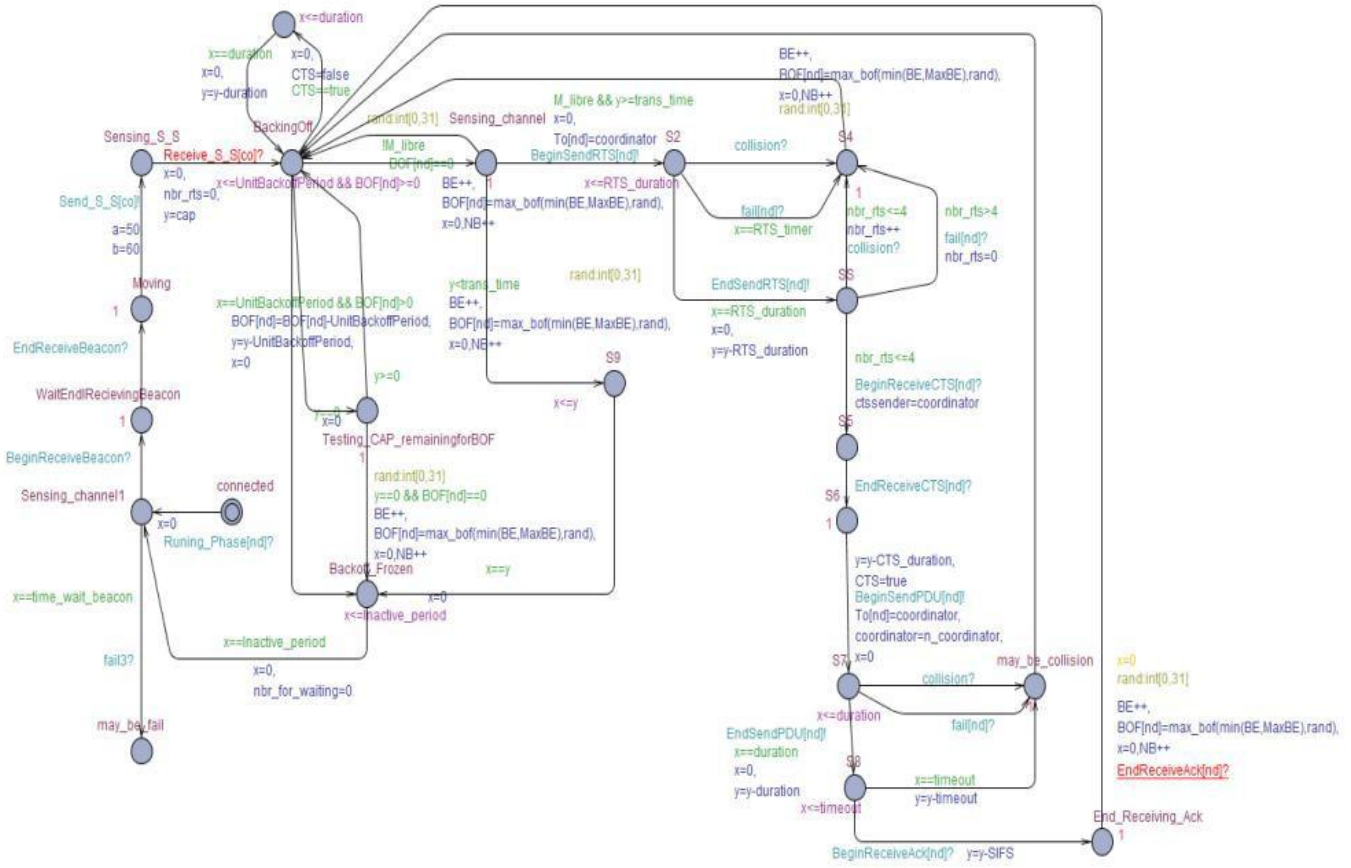

Fig. 2. Probabilistic model of a mobile node in the runing phase.

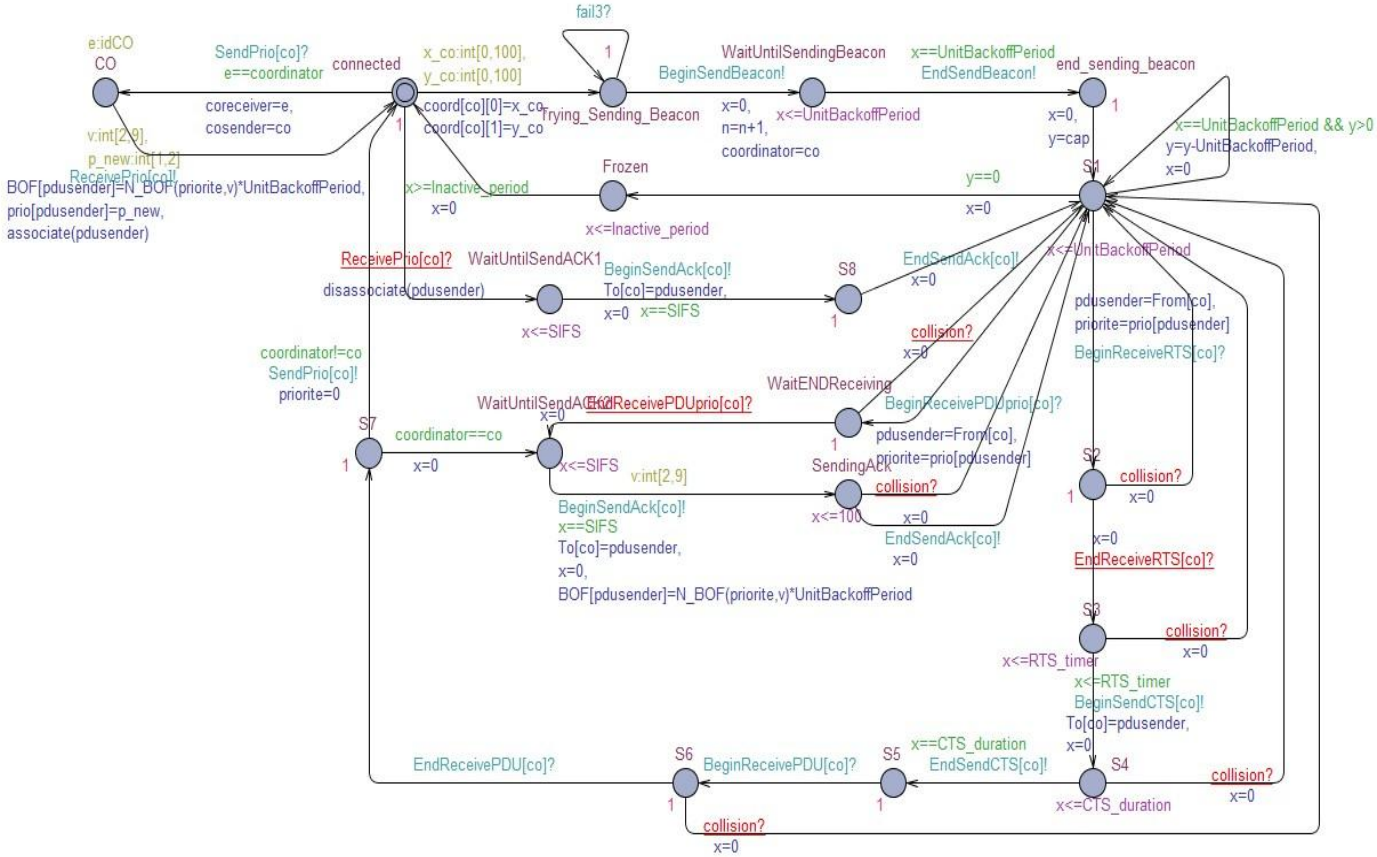

Fig. 3. Probabilistic model of a coordinator.

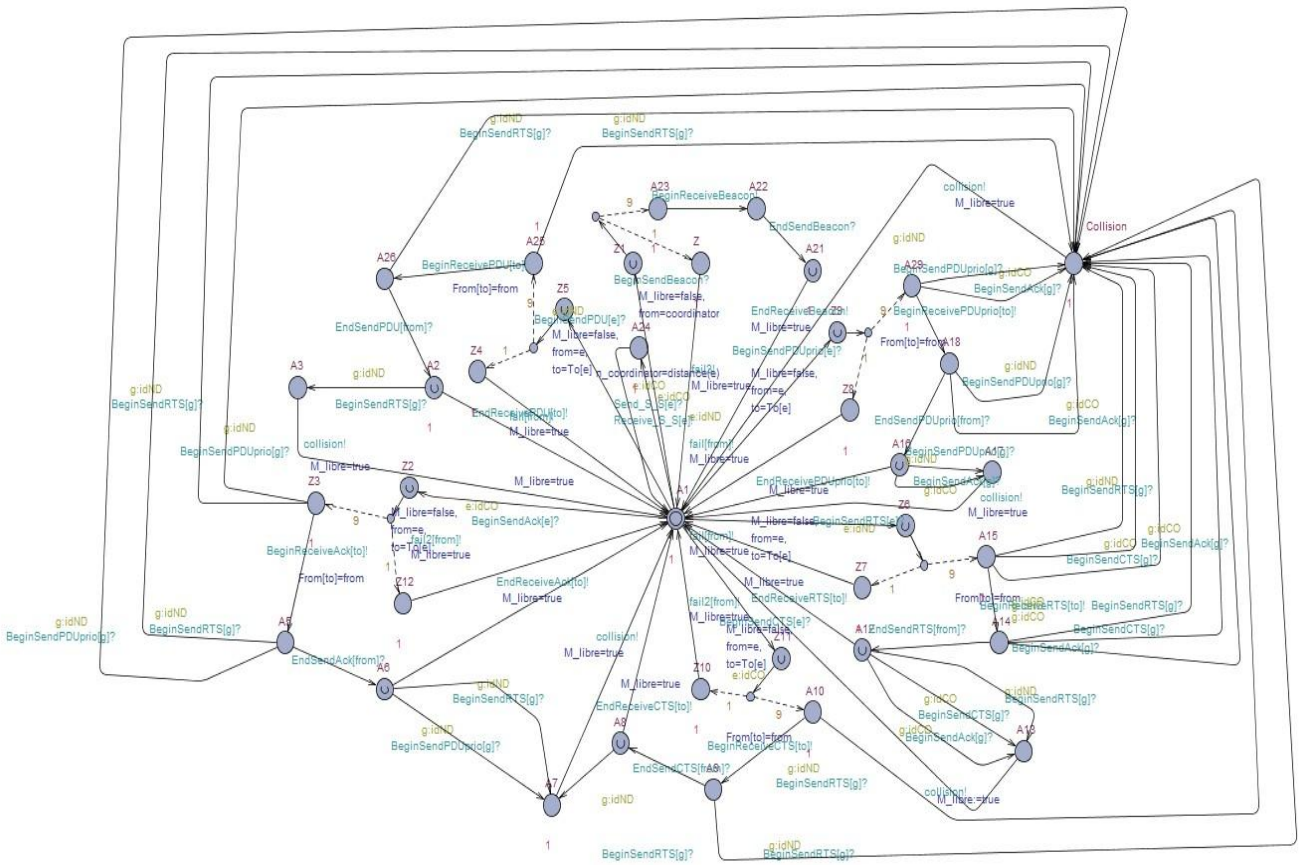

Fig. 4. Probabilistic model of the medium.

association decreases as the number of nodes increases. However, we note that this is not too clear due to the duration of the runtime. Fig. 5 and Fig. 6 confirm the expected result by increasing the runtime value.

Fig. 7 shows the probability of finishing a transmission by

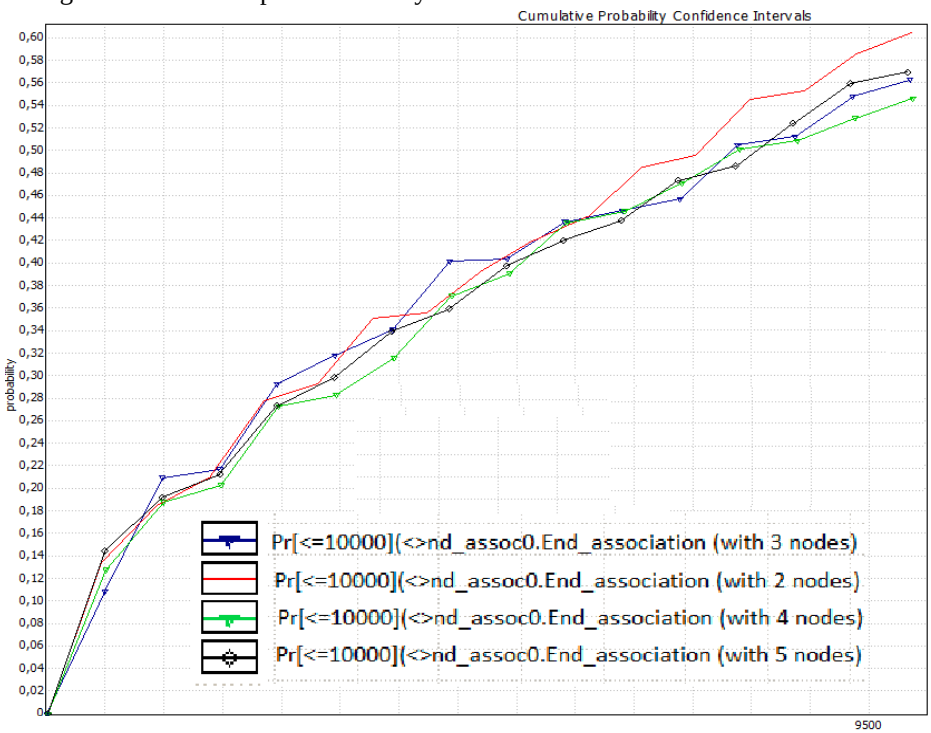

Fig. 5. Probability of finishing the association depending on the number of nodes with runtime <= 10^4.

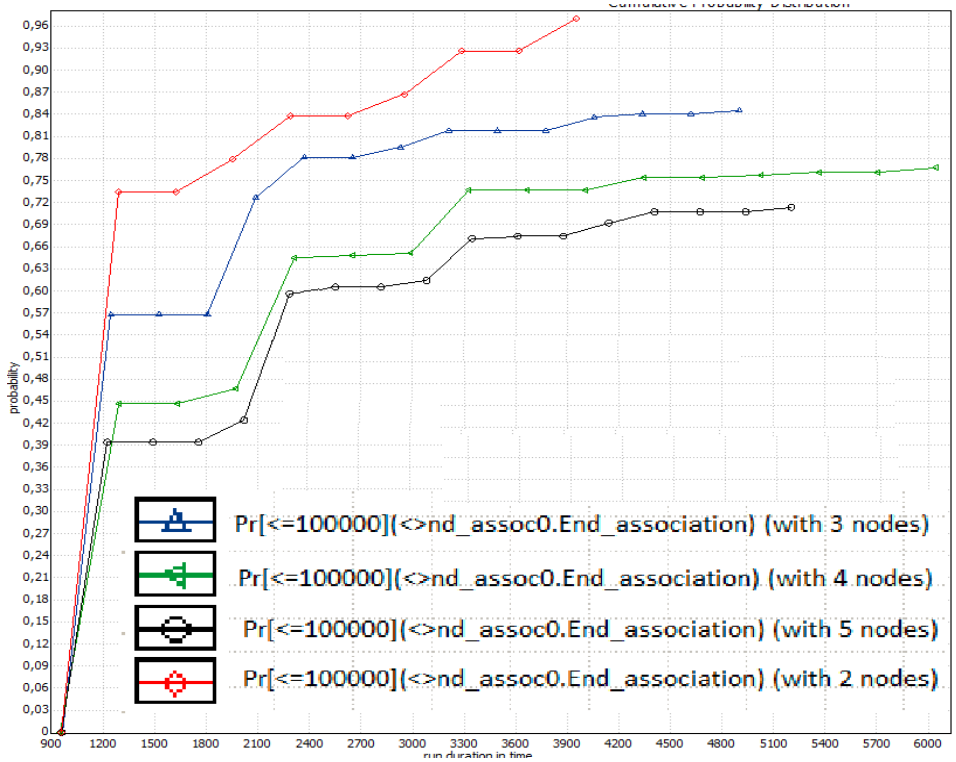

Fig. 6. Probability of finishing the association depending on the number of nodes with runtime <= 10^5.

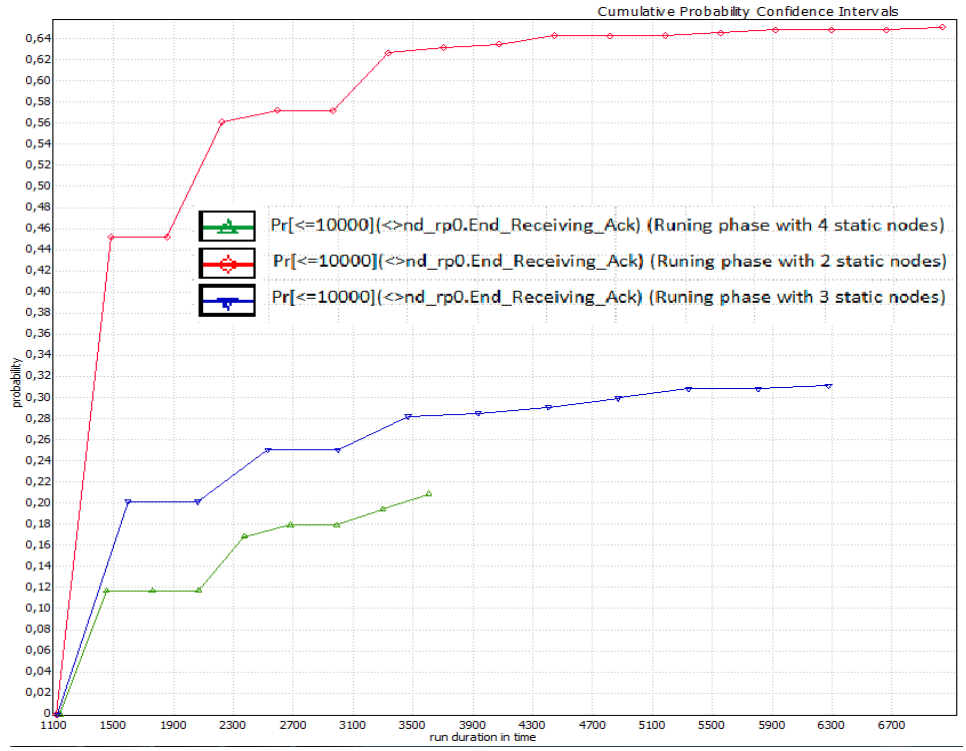

Fig. 7. Probability of receiving Ack deppending on number of nodes.

receiving an ACK, according to the number of nodes, for a duration of runtime <= 10^3. Likewise, we studied the probability of a collision depending on the number of static and mobile nodes in a runtime <= 10^3 as depicted in Fig. 8.

The probability of a collision as a function of the number of nodes and depending on duration of runtime is depicted in Fig. 9 and Fig. 10, respectively.

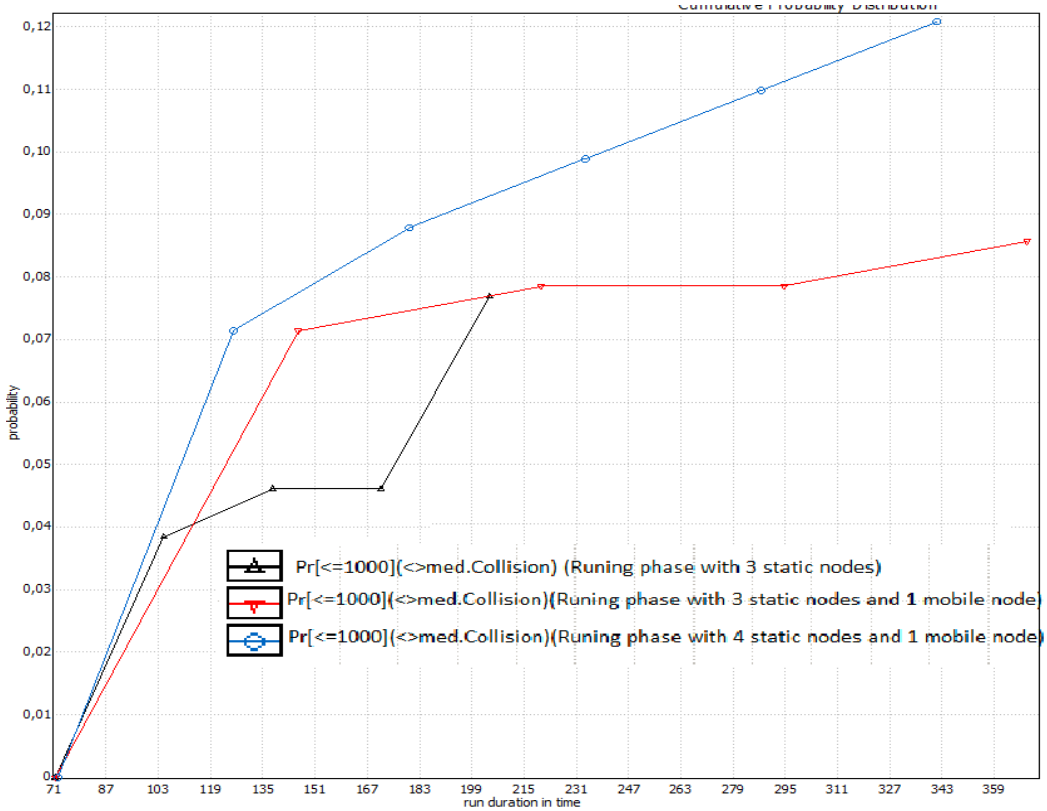

Fig. 8. Probability of having collision depending on the number of static and mobile nodes.

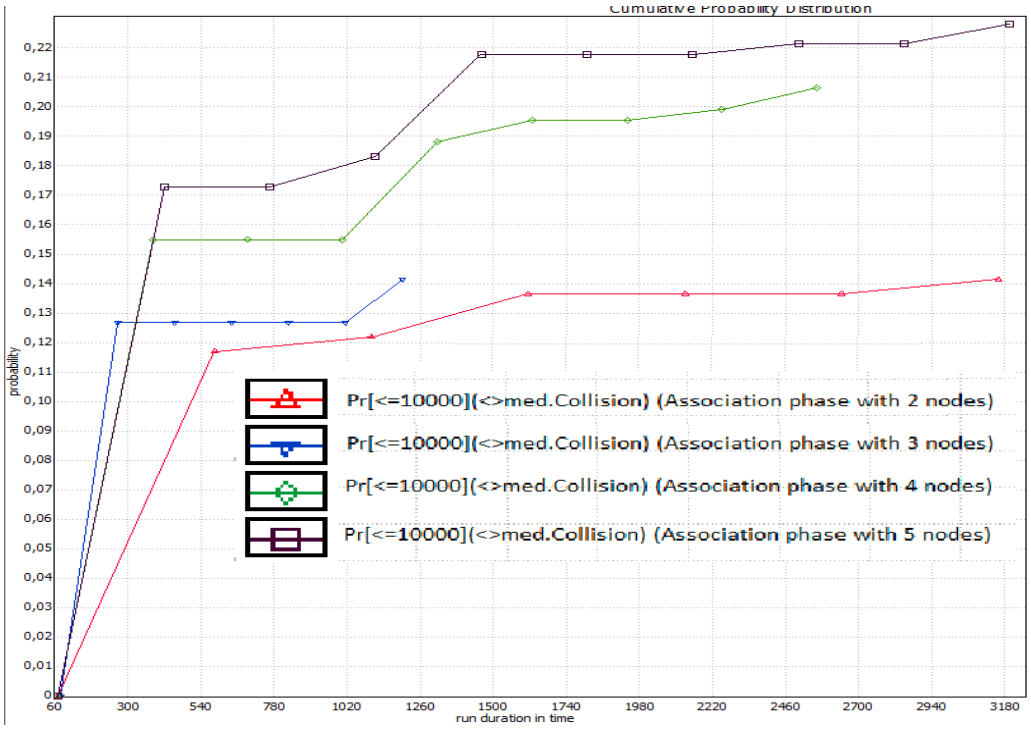

Fig. 9. Probability of having collision depending on number of nodes.

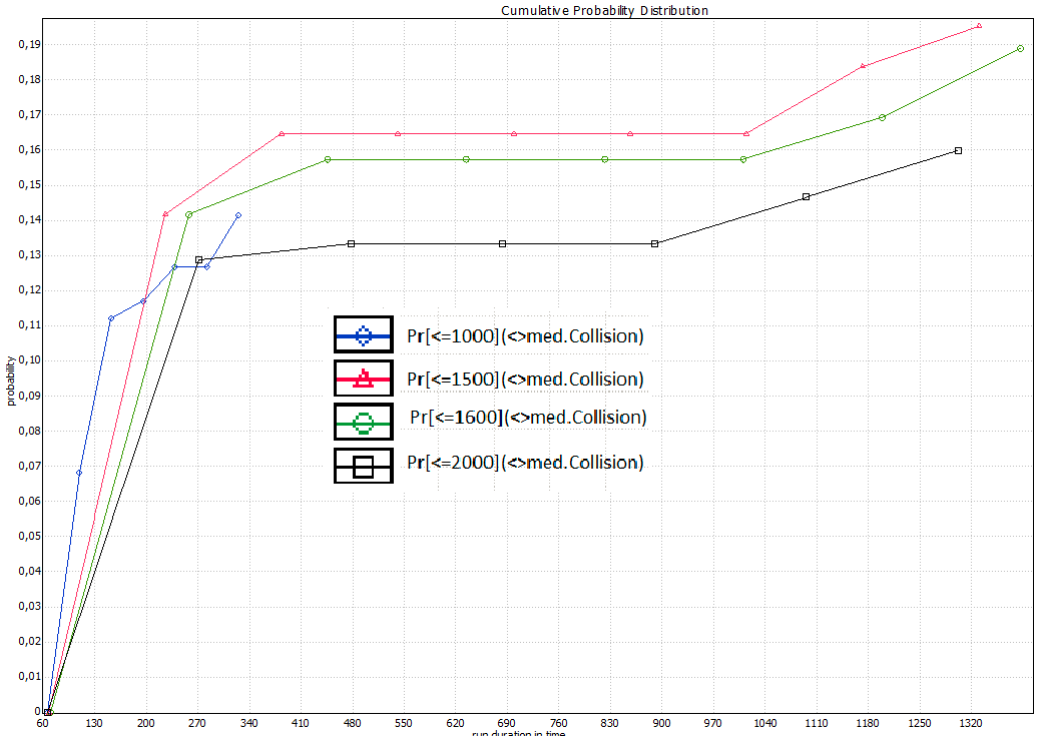

Fig. 10. Probability of having collision depending on the runtime.

V. Conclusion

In this paper, a formal modeling of an access protocol in wireless sensor networks with mobile nodes was presented. This protocol called Collision Free Mobility Adaptive MAC (CFMA/MAC) protocol was proposed to minimize collisions in mobile environments. In order to model this protocol, we began studying the protocol exhaustively by a semi formal modeling with UML then, a formal modeling with Probabilistic Timed Automata (PTAs). For the verification of this protocol, the Statistical Model Checking (SMC) provided in UPPAAL tool was used. Several indispensible properties in networking were verified such as reachability, safety and liveness. Likewise, many important metrics, related to this protocol, were analyzed such as the number of collisions, the success rate of transmission, the success rate of association, etc.).

This work can be extended on several levels. In the future, we plan to consider other features such as a higher number of nodes, other properties and a refined comparison with the existing protocols as well as a proposal of a complete approach for the transition from the formal specifications to the generation of executable code on the nodes of the network.

References

[1] What is uml? http://www.uml.org/. Accessed: 2017-06-29.

[2] I. F. Akyildiz, Weilian Su, Y. Sankarasubramaniam, and E. Cayirci. A survey on sensor networks. IEEE Communications Magazine, 40(8):102–114, Aug 2002.

[3] Paolo Ballarini and Alice Miller. Model checking medium access control for sensor networks. In Proceedings of the 2nd International Symposium on Leveraging Applications of Formal Methods, (ISoLA'06), pages 255–262, 2006.

[4] Cinzia Bernardeschi, Paolo Masci, and Holger Pfeifer. Analysis of Wireless Sensor Network Protocols in Dynamic Scenarios, pages 105–119. Springer Berlin Heidelberg, Berlin, Heidelberg, 2009.

[5] Juan Antonio Cordero. A probabilistic study of the delay caused by jittering in wireless flooding. Wireless Personal Communications, 73(3):415–439, Dec 2013.

[6] Alexandre David, Kim G. Larsen, Axel Legay, Marius Mikuˇaionis, and Danny BOgsted Poulsen. Uppaal smc tutorial. Int. J. Softw. Tools Technol. Transf., 17(4):397–415, August 2015.

[7] Maissa Elleuch, Osman Hasan, Sofine Tahar, and Mohamed Abid. Formal probabilistic analysis of a wireless sensor network for forest fire detection. In Adel Bouhoula, Tetsuo Ida, and Fairouz Kamareddine, editors, SCSS, volume 122 of EPTCS, pages 1–9, 2012.

[8] Saurabh Ganeriwal, Ram Kumar, and Mani B. Srivastava. Timing-sync protocol for sensor networks. In Proceedings of the 1st International Conference on Embedded Networked Sensor Systems, SenSys '03, pages 138–149, New York, NY, USA, 2003. ACM.

[9] Y. Hammal, J. Ben-Othman, L. Mokdad, and A. Abdelli. Formal modeling and verification of an enhanced variant of the ieee 802.11 csma/ca protocol. Journal of Communications and Networks, 16(4):385–396, Aug 2014.

[10] J. He, P. Cheng, J. Chen, L. Shi, and R. Lu. Time synchronization for random mobile sensor networks. IEEE Transactions on Vehicular Technology, 63(8):3935–3946, Oct 2014.

[11] Zohra Hmidi, La¨ıd Kahloul, Benharzallah Saber, and Cherifa Othmane. Statistical model checking of CSMA/CA in wsns. In Proceedings of the 10th Workshop on Verification and Evaluation of Computer and Communication System, VECoS 2016, Tunis, Tunisia, October 6-7, 2016., pages 27–42, 2016.

[12] Tien-Shin Ho and Kwang-Cheng Chen. Performance analysis of ieee 802.11 csma/ca medium access control protocol. In Personal, Indoor and Mobile Radio Communications, 1996. PIMRC'96., Seventh IEEE International Symposium on, volume 2, pages 407–411 vol.2, Oct 1996.

[13] Kurt Jensen, Lars Michael Kristensen, and Lisa Wells. Coloured petri nets and cpn tools for modelling and validation of concurrent systems. International Journal on Software Tools for Technology Transfer, 9(3):213–254, Jun 2007.

[14] Bilal Muhammad Khan and Falah H. Ali. Collision free mobility adaptive (cfma) mac for wireless sensor networks. Telecommunication Systems, 52(4):2459–2474, Apr 2013.

[15] S. A. Ajith Kumar and Kent I. F. Simonsen. Towards a model-based development approach for wireless sensor-actuator network protocols. In Proceedings of the 4th ACM SIGBED International Workshop on

Design, Modeling, and Evaluation of Cyber-Physical Systems, CyPhy'14, pages 35–39, New York, NY, USA, 2014. ACM.

[16] Marta Kwiatkowska, Gethin Norman, and Jeremy Sproston. Symbolic Computation of Maximal Probabilisti Reachability, pages 169–183. Springer Berlin Heidelberg, Berlin, Heidelberg, 2001.

[17] Marta Kwiatkowska, Gethin Norman, and Jeremy Sproston. Probabilistic Model Checking of the IEEE 802.11 Wireless Local Area Network Protocol, pages 169–187.Springer Berlin Heidelberg, Berlin, Heidelberg, 2002.

[18] Marta Kwiatkowska, Gethin Norman, and Jeremy Sproston. Probabilistic Model Checking of the IEEE 802.11 Wireless Local Area Network Protocol, pages 169–187. Springer Berlin Heidelberg, Berlin, Heidelberg, 2002.

[19] Z. Li, Y. Liu, M. Li, J. Wang, and Z. Cao. Exploiting ubiquitous data collection for mobile users in wireless sensor networks. IEEE Transactions on Parallel and Distributed Systems, 24(2):312–326, Feb 2013.

[20] M. J. Nene, R. S. Deodhar, and L. M. Patnaik. Algorithm for autonomous reorganization of mobile wireless camera sensor networks to improve coverage. IEEE Sensors Journal, 15(8):4428–4441, Aug 2015.

[21] K. Saghar, W. Henderson, D. Kendall, and A. Bouridane. Formal modelling of a robust wireless sensor network routing protocol. In 2010 NASA/ESA Conference on Adaptive Hardware and Systems, pages 281–288, June 2010.

[22] Koushik Sen, Mahesh Viswanathan, and Gul Agha. Statistical model checking of black-box probabilistic systems. In Rajeev Alur and Doron Peled, editors, CAV, pages 202–215, 2004.

[23] C. Tunca, S. Isik, M. Y. Donmez, and C. Ersoy. Ring routing: An energy-efficient routing protocol for wireless sensor networks with a mobile sink. IEEE Transactions on Mobile Computing, 14(9):1947–1960, Sept 2015.

[24] Hongqiang Zhai, Younggoo Kwon, and Yuguang Fang. Performance analysis of ieee 802.11 mac protocols in wireless lans. Wireless Communications and Mobile Computing, 4(8):917–931, 2004.

[25] C. Zhang and M. Zhou. A stochastic petri net-approach to modeling and analysis of ad hoc network. In International Conference on Information Technology: Research and Education, 2003. Proceedings. ITRE2003., pages 152–156, Aug 2003.

[26] Fengling Zhang, Lei Bu, Linzhang Wang, Jianhua Zhao, Xin Chen, Tian Zhang, and Xuandong Li. Modeling and evaluation of wireless sensor network protocols by stochastic timed automata. Electronic Notes in Theoretical Computer Science, 296:261 – 277, 2013. Proceedings the Sixth International Workshop on the Practical Application of Stochastic Modelling (PASM) and the Eleventh International Workshop on Parallel and Distributed Methods in Verification (PDMC).