ABSTRACTIONS TO EXPLOIT THE SAVINGS OF APERIODIC CONTROL SCHEMES

MANUEL MAZO JR., DELFT UNIVERSITY OF TECHNOLOGY

ABSTRACT. Modern control systems are often implemented as networked systems, in which bandwidth of a communication medium is shared among a number of applications. Furthermore, often the act of communicating also has an energy impact on the system infrastructure, e.g. in the case of wireless control systems. In the last decade the study of controller implementation strategies aiming at reducing the communication footprint, to save bandwidth (and energy), has thus attracted great attention. Arguably, one of the most promising implementation paradigms in the literature is that of event-triggered control (ETC), in which communications are triggered by the state of the plant itself, which makes the system *communicate only when necessary* to retain stability of the closed-loop.

ETC implementations, while reducing drastically the amount of required bandwidth, result in aperiodic transmissions whose time of occurrence are highly unpredictable, leading to difficulties for scheduling such systems. Such difficulties usually imply that the freed bandwidth may not be reusable by other (real-time) applications, and that energy savings may be completely lost, thus rendering ETC schemes inefficient.

In this series of lectures I'll describe a possible solution to the ETC scheduling problem through the construction of timed-automata models for the ETC systems' traffic. I will start introducing ETC and illustrating the impact of the problem on some examples from our experimental work. I will then introduce the notions of symbolic abstractions of control systems, simulation relations and timed-automata, and I'll show how all of those come together in our approach to schedule ETC. I'll finalize the course describing our most recent advances on how to construct ETC traffic models, and the available tools to use them for controller scheduling.

Content overview

Lecture 1: Event-triggered Control and the Scheduling problem.

- Introduction to the ETC scheduling problem
- Event-triggered control
- Self-triggered control
- Overview of the proposed solution

References: [Tab07, HJT12, MJSKAH18]

Lecture 2: Symbolic abstractions, simulation relations, and timed-automata.

- Symbolic abstractions for control
- (Alternating) (bi-)simulation relations
- Timed-automata models
- Tools

References: [Tab09, AD94, BFLM11, MDT10]

Lecture 3: Scheduling ETC via traffic abstractions.

- Construction of timing abstractions for linear ETC
- Construction of timing abstractions for non-linear ETC
- Automatic synthesis (quasi-optimal) schedulers
- Tools

References: [MJSKAH18, KM18, DMJ19, AMJ16, BLR05]

References

[AD94] Rajeev Alur and David L Dill. A theory of timed automata. *Theoretical computer science*, 126(2):183–235, 1994.

[AMJ16] Dieky Adzkiya and Manuel Mazo Jr. Scheduling of event-triggered networked control systems using timed game automata. *arXiv preprint arXiv:1610.03729*, 2016.

[BFLM11] Patricia Bouyer, Uli Fahrenberg, Kim Guldstrand Larsen, and Nicolas Markey. Quantitative analysis of real-time systems using priced timed automata. *Communications of the ACM*, 54(9):78–87, 2011.

[BLR05] Gerd Behrmann, Kim G Larsen, and Jacob I Rasmussen. Optimal scheduling using priced timed automata. *ACM SIGMETRICS Performance Evaluation Review*, 32(4):34–40, 2005.

[DMJ19] Giannis Delimpaltadakis and Manuel Mazo Jr. Isochronous partitions for region-based self-triggered control. *arXiv preprint arXiv:1904.08788*, 2019.

[HJT12] WPMH Heemels, Karl Henrik Johansson, and Paulo Tabuada. An introduction to event-triggered and self-triggered control. In *2012 IEEE 51st IEEE Conference on Decision and Control (CDC)*, pages 3270–3285. IEEE, 2012.

[KM18] Arman Sharifi Kolarijani and Manuel Mazo. Formal traffic characterization of lti event-triggered control systems. *IEEE Transactions on Control of Network Systems*, 5(1):274–283, 2018.

[MDT10] Manuel Mazo, Anna Davitian, and Paulo Tabuada. Pessoa: A tool for embedded controller synthesis. In *International Conference on Computer Aided Verification*, pages 566–569. Springer, 2010.

[MJSKAH18] M Mazo Jr, A Sharifi-Kolarijani, D Adzkiya, and C Hop. Abstracted models for scheduling of event-triggered control data traffic. In *Control Subject to Computational and Communication Constraints*, pages 197–217. Springer, 2018.

[Tab07] Paulo Tabuada. Event-triggered real-time scheduling of stabilizing control tasks. *IEEE Transactions on Automatic Control*, 52(9):1680–1685, 2007.

[Tab09] Paulo Tabuada. *Verification and control of hybrid systems: a symbolic approach*. Springer Science & Business Media, 2009.