Next Generation Resilient Cyber-Physical Systems (One Page Extended Abstract)

Michel Barbeau, *Member IEEE*, Georg Carle, *Member IEEE*,
Joaquin Garcia-Alfaro ✉, *Senior Member, IEEE*,
and Vicenç Torra, *Fellow Member, IEEE*

CYber-Physical Systems (CPS) encompass physical processes observed and controlled through a computer network. Signals to actuators and feedback from sensors are exchanged with a controller using, e.g., Ethernet and TCP/IP networks. The advantages of such an architecture are flexibility and relatively low deployment cost. Nevertheless, the networking aspect of CPS opens the door to cyber-physical attacks, in addition to failures and faults.

Analysis of past incidents highlights the advanced knowledge degree of the adversaries perpetrating the attacks. Adversaries are smart and they can learn. Their sophistication is such that they can fool the controllers forging false feedback. Hence, a fundamental CPS security problem is the *feedback truthfulness problem*, in which controllers need to distinguish unintentional failures from malicious attacks. Although similar in practice, their management must be different. While faults must be corrected using the appropriate feedback, attacks have to be handled with with appropriated remediation plans. Building systems capable to managing such issues will lead to *resilient by construction* CPS designs.

Resilience refers to the capacity of a system to recover from disruptions. It can be seen as the mechanisms present in a system to regulate its safety and security and to recover from adverse events. Resilience includes actions and plans that are deployed before, during and after adverse events take place. Resilience is a historical term used as a descriptor in complex fields, from psychology and medicine to civil and military engineering. In cybersecurity, it relates to the idea of how a complex system bounces back from a disruption, as well as all the possible post-disruption strategies followed after the events are recognized.

To improve resilience from the cybersecurity standpoint relies on enforcing security stacks, in terms of identifying the system weaknesses (e.g., in their software and infrastructure themselves) that could potentially be controlled by a skilled adversary with the purpose of disrupting the system. Management in terms of identifying vulnerabilities must be followed as well by assessment of incidents, service continuity and, in general, any risks affecting the system. These aforementioned management perspectives must be driven by resilience thinking in the form of defending back from disruptive or adverse events. In other words, attacks against the availability of a given service, as well as any incident leading to security breaches, must be quickly absorbed.

Today's security stacks solutions, from in-depth defense techniques (e.g., firewalls and cryptography) to control-theoretic detection techniques, are not enough. These approaches aim to prevent system breaches from happening. However, several stories of attacks and disruption of CPS told in the media are evidence that new solutions must be designed to defend the system beyond security breaches. We argue that new security stacks must be included in tomorrow's resilient CPS to manage the occurrence of breaches. New stacks must manage and take control over adversarial actions that will persistently occur in a CPS. They must be built taking on the adversary mindset, predicting its intentions and adequately mitigating the effects. Tomorrow's CPS must be equipped with learning capabilities, assisting the CPS to anticipate the adversary intentions and transform them into regular actions. These potential new stacks will enable the evolution towards CPS that are resilient beyond breach.

The essence of the war between adversaries and defenders is knowledge. In the same way that all current (today's) systems are designed with high safety technologies and protocols, in the future they will be designed with adaptive knowledge capabilities. Will artificial intelligence (AI) and machine learning communities play a role to support this evolution? If we explore recent results in those communities, and analyze whether they might shed new light on the design of future resilient CPS, three promising techniques can potentially help to the dynamics of the game: *machine learning*, *fuzzy decisional systems*, and *quantum search*.

The subfields of machine learning and search provide a large set of techniques appropriate for cyber-physical resilience. There are three main machine learning paradigms, namely, supervised, unsupervised and reinforcement. Supervised and reinforcement learning can be used for the purpose of system identification, an enabler for both attacks and defenses. The design of resilience plans can leverage AI heuristic search to speedup decision taking during the execution of a resilience plan. The adaptive control that resilience requires may be obtained using the fuzzy decisional approach. Quantum techniques can eventually perform searches with time complexity that is data size independent.

M. Barbeau, Carleton University, School of Computer Science, Canada. E-mail: barbeau@scs.carleton.ca

G. Carle, Technical University of Munich, Department of Informatics, Chair of Network Architectures and Services, Germany. E-mail: carle@net.in.tum.de

J. Garcia-Alfaro ✉, Institut Polytechnique de Paris, CNRS UMR 5157 SAMOVAR, Télécom SudParis, France. E-mail: jgalfaro@ieee.org

V. Torra, National University of Ireland, Maynooth, Hamilton Institute, Ireland. E-mail: vtorra@ieee.org

Manuscript received June 1st, 2019; revised xxxx.