Edge-Based Runtime Verification for the Internet of Things

Christos Tsigkanos*, Marcello M. Bersani†, Pantelis A. Frangoudis*, Schahram Dustdar*
*TU Wien, Vienna, Austria
{c.tsigkanos, p.frangoudis, dustdar}@dsg.tuwien.ac.at
†Politecnico di Milano, Milan, Italy
bersani@elet.polimi.it

[J1C2 Presentation Abstract at IEEE SERVICES 2021 for IEEE Transactions on Services Computing DOI TSC.2021.3074956]

Complex distributed systems such as the ones induced by Internet of Things (IoT) deployments, are expected to operate in compliance to their requirements. This can be checked by inspecting events flowing throughout the system, typically originating from end-devices and reflecting arbitrary actions, changes in state or sensing. Such events typically reflect the behavior of the overall IoT system – they may indicate executions which satisfy or violate its requirements.

Supporting such validation in practice however, is challenging. Firstly, the sheer number of devices and their heterogeneity inherent in IoT systems require dedicated software architectures – typical cloud-based deployments are often not applicable. Secondly, communication particularities of the IoT domain need to be taken into account, since devices may be connected through a plethora of networking technologies exhibiting different characteristics, such as low-power wide-area networks (LPWAN). Finally, the volume and velocity of the events generated in realistic IoT systems can saturate network links and centralized processing schemes.

We present [1] a service-based software architecture and technical framework supporting runtime verification for decentralized edge-intensive systems. At the lowest level, systems we consider are comprised of resource-constrained devices connected over wide area networks generating events. Monitors are deployed on edge components, receiving events originating from end-devices and other edge nodes. Properties expressing desired system requirements are evaluated on each edge monitor in a runtime fashion. The system exhibits decentralization, since property evaluation occurs locally on an edge node, while evaluation verdicts possibly affecting satisfaction of other properties on other edge nodes are propagated accordingly. We assume that requirements to be satisfied by the system under design are specified in terms of assertions in a temporal logic. We subsequently leverage results on runtime verification and devise a practical distributed systems architecture and framework that can support evaluation of properties. Our framework achieves decentralization in two dimensions: (i) events are evaluated locally within the scope of an edge node, avoiding central or cloud-based collection that can incur cross-network overhead, and (ii) properties evaluated in edge nodes that affect satisfaction of others are propagated throughout the hierarchically structured system.

Systems we consider are composed of i) (possibly resource-constrained) edge computers placed near ii) sensing end-devices, as well as potentially iii) cloud infrastructure. We advocate decentralization, as the edge is a first-class entity in our approach, responsible for evaluating properties on events originating from IoT devices within its scope (such as a local administrative domain or wireless network) but bearing no dependencies besides events needed for checking in other edge nodes or the cloud.

Our framework [1] utilizes Metric First-Order Temporal Logic (MFOTL), a formalism operating on traces of events. Our motivations for choosing the formalism are (i) its expressiveness, as MFOTL has seen applications on systems ranging from financial to cyber-physical, and (ii) the fact that it is well-defined and has well-studied theoretical semantics and properties, both rendering practical adoption and tool support easier. We contextify the framework advocated within the wide domain of IoT monitoring, but stress particularly runtime verification as its technical domain.

To provide concrete evidence of the applicability of the proposed architecture and technical framework, we first illustrate how runtime verification can be achieved in practice on a case study of a spatially-distributed parking system in a large metropolitan area, drawing from publicly available parking data from the city of Los Angeles. We then investigate the feasibility of our design to operate in resource-constrained edge computing environments over a testbed instatiation. Thereupon, we evaluate performance and capacity limits of different hardware classes, from small single-board computers to server-class data center hosts, under monitoring workloads of varying intensity, for end-devices communicating over LoRaWAN, a popular LPWAN technology.

References

[1] C. Tsigkanos, M. M. Bersani, P. A. Frangoudis, and S. Dustdar, "Edge-based runtime verification for the internet of things," *IEEE Transactions on Services Computing*, 2021.

2642-939X/21/$31.00 ©2021 IEEE
DOI 10.1109/SERVICES51467.2021.00027