School of Computing, Engineering, and the Built Environment
Edinburgh Napier University

PHD STUDENT PROJECT

Application instructions:
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Prospective candidates are encouraged to contact the Director of Studies (see details below) to discuss the project and their suitability for it.

Project details

Supervisory Team:

- DIRECTOR OF STUDY: Dr Amjad Ullah (Email: a.ullah@napier.ac.uk)
- 2ND SUPERVISOR: tbc

Subject Group: Computer Science

Research Areas: Artificial Intelligence, Computer Architecture, Data Science, Internet of Things, Machine Learning, Networks, Software Engineering

Project Title: The Science of Self-Organizing Swarms for Distributed Edge Infrastructure

Project description:

The next generation of intelligent cyber-physical and IoT systems powered by AI are becoming an essential part of our environment. Smart cities, smart manufacturing, augmented reality, industry 4.0, and self-driving cars are a few examples of the wide range of domains, where the applicability of such systems is extremely impactful. However, the efficient management of these complex applications on the distributed edge infrastructure — often referred to as the Cloud-to-Edge compute continuum — including their deployment on heterogeneous computing resources and their run-time reconfiguration to take into various considerations such as resource requirements and constraints, potential volatility of resources, or dynamically changing security requirements, raises significant challenges.

The efficient and effective management and processing of huge amounts of data in such systems has to deal with versatile requirements such as the need to process some data locally rather than in a central cloud location due to regulations, performance constraints, low latency analytics closer to the source, privacy and security constraints, context-awareness, time- and location awareness, simultaneous access to geographically distributed arrays of sensors, access to remote localised heterogeneous computational resources, as well as access to large-scale on-the-fly multi-cloud computational resources

[1]. To deal with this complexity, a resource management solution — often referred to as an orchestrator — is used to automate, and manage the overall requirements including the responsibility to discover, optimise, and manage the required resources, deployment and management of application life-cycle management whilst ensuring system stated performance objectives.

[2]. Most of the available solutions mainly follow a centralised model, where an entity — often operating from the cloud — gather, process, analyse, and orchestrate from a central location. Such a model works well for cloud-only systems. However, considering the decentralised nature of the edge infrastructure, where resources span across different layers of clouds, fog and edge, a centralized model fosters significant drawbacks, e.g. communication overhead consists of the continuous transfer of recurrent monitoring data from different administrative domains to a central location, the associated data privacy and security issues, volatile connectivity, lack of scalability, single point of failure, and being an easy central target for cyber-attacks.

[3]. In contrast, a decentralised orchestration solution is a more natural fit considering the distributed nature of edge infrastructure. Hence, more recently, with the advancement in edge infrastructure, there is a lot of focus on the development of a new class of distributed solutions for the management and optimisation of distributed edge infrastructures [4, 5, 6, 7]. In the same realm, this project aims to explore and investigate the possibility of using swarm-inspired self-organised coordination mechanisms for devising orchestration strategies to manage the automated deployment and life-cycle management of IoT applications on distributed edge infrastructure whilst complying with system-stated constraints and performance objectives.

Our research in this project is centred around the distribution of intelligent orchestration agents across the edge infrastructure, the understanding of their underlying characteristics required for self-organisation, The dynamic formulation of swarms, and their coordination amongst each other for the accomplishment of the available tasks regarding achieving application objectives. Overall, this project aims to achieve the following key objectives:
1. To investigate, understand and benchmark the notion of decentralisation within the context of orchestration solutions.
2. To describe, map, and formalise the problem of application and resource management on distributed edge infrastructure within the context of self-organising swarms.
3. To implement an initial prototype based on a simple self-organising swarms-based system using a simulation environment (such as iFogSim [8]) to evaluate and benchmark the effectiveness of such an approach for the management of distributed edge infrastructures.

References:

[1] A. Yousefpour, C. Fung, T. Nguyen, K. Kadiyala, F. Jalali, A. Niakanlahiji, J. Kong, and J. P. Jue, “All one needs to know about fog computing and related edge computing paradigms: A complete survey,” Journal of Systems Architecture, vol. 98, pp. 289–330, 2019.

[2] O. Tomarchio, D. Calcaterra, and G. D. Modica, “Cloud resource orchestration in the multi-cloud landscape: a systematic review of existing frameworks,” Journal of Cloud Computing, vol. 9, pp. 1–24, 2020.

[3] C.-H. Hong and B. Varghese, “Resource management in fog/edge computing: a survey on architectures, infrastructure, and algorithms,” ACM Computing Surveys (CSUR), vol. 52, no. 5, pp. 1–37, 2019.

4] X. Masip-Bruin, E. Mar´ın-Tordera, S. S´anchez-L´opez, J. Garcia, A. Jukan, A. Juan Ferrer, A. Queralt, A. Salis, A. Bartoli, M. Cankar, et al., “Managing the cloud continuum: Lessons learnt from a real fog-to cloud deployment,” Sensors, vol. 21, no. 9, p. 2974, 2021.

[5] G. Castellano, F. Esposito, and F. Risso, “A service-defined approach for orchestration of heterogeneous applications in cloud/edge platforms,” IEEE Transactions on Network and Service Management, vol. 16, no. 4, pp. 1404–1418, 2019.

[6] T. Yeh and S. Yu, “Realizing dynamic resource orchestration on cloud systems in the cloud-to-edge continuum,” Journal of Parallel and Distributed Computing, vol. 160, pp. 100–109, 2022.

[7] F. Smirnov, C. Engelhardt, J. Mittelberger, B. Pourmohseni, and T. Fahringer, “Apollo: Towards an efficient distributed orchestration of serverless function compositions in the cloud-edge continuum,” in Proceedings of the 14th IEEE/ACM International Conference on Utility and Cloud Computing, pp. 1–10, 2021.

[8] H. Gupta, A. Vahid Dastjerdi, S. K. Ghosh, and R. Buyya, “ifogsim: A toolkit for modeling and simulation of resource management techniques in the internet of things, edge and fog computing environments,” Software: Practice and Experience, vol. 47, no. 9, pp. 1275–1296, 2017.

[9] A. Ullah, H. Dagdeviren, R. C. Ariyattu, J. DesLauriers, T. Kiss, and J. Bowden, “Micado-edge: Towards an application-level orchestrator for the cloud-to-edge computing continuum,” Journal of Grid Computing, vol. 19, pp. 1–28, 2021.

Candidate characteristics

Education:

Minimum 2:1 degree in Computer Science

Subject knowledge:

Software engineering, computer programming, cloud technologies, and machine learning.

Essential attributes:

- Experience of fundamental software engineering
- Competent in one (or some) programming languages
- Knowledge of Cloud, IoT, Machine learning, and Microservices architecture
- Good written and oral communication skills
- Strong motivation, with evidence of independent research skills relevant to the project
- Good time management