The Doctoral Program Form contains, year by year, the description of the PhD program of each Doctoral student. This form must be submitted to the PhD coordinator with roughly the following timing:

- by the end of February of the first year for first year students
- before the admission to the second year by perspective second year students
- before the admission to the third year by perspective third year students

The Doctoral Program Proposal is approved by the PhD board shortly after submission.

The Doctoral Program requirements place formalized emphasis on methodology and mastery of fundamental and applied engineering systems concepts. A Doctoral Program Proposal should be constructed in agreement with the Faculty mentor, that is the supervisor or tutor, by complying to the requirements, described in the Tables below.

### SEMINARS AND LABORATORY ACTIVITIES: 6 CFU¹

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type</th>
<th>Duration / period</th>
<th>CFU²</th>
<th>Motivation for selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insert title of activity (seminar, laboratory sessions) and a description of goals and expected results</td>
<td>Insert here Activity type, e.g. seminar, lab sessions</td>
<td>Insert duration (measured in hours or days) and period of year</td>
<td>Insert here a detailed explanation of why the activity was selected and included in the doctoral program, and how it connects with the research area of the PhD student.</td>
<td></td>
</tr>
<tr>
<td>Integration of the Oblivious Random Walk Source Routing and DQN Adaptive Routing algorithms in the OMNeT++ model of the ExaNeSt Tier-1 n-dimensional Torus network.</td>
<td>Laboratory</td>
<td>Nov. 2018 – Mar. 2019 120 hours</td>
<td>6</td>
<td>The topic of the thesis is the development of a novel routing algorithm for n-dimensional Torus network interconnects. During second year of PhD program, the candidate developed two novel routing algorithms (Oblivious Random Walk Source Routing and DQN Adaptive Routing) and the OMNeT++ simulator framework of the ExaNeSt torus network. The in order to validate and assess the performances of these algorithms under various traffic patterns, including those generated by the execution on a parallel machine of the Human Brain Project spiking neural network simulator, their OMNeT++ model will be developed and integrated in the network simulation framework. Simulation results will likely provide hints to further refinements on the algorithms.</td>
</tr>
</tbody>
</table>

Total CFU 6

### ADDITIONAL INDEPENDENT FORMATION AND RESEARCH ACTIVITIES: 6 CFU³

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type</th>
<th>Duration / period</th>
<th>CFU⁴</th>
<th>Motivation for selection</th>
</tr>
</thead>
</table>

¹ Please insert lines as required/appropriate, and for each line complete each column of the Table.
² Indicate here the CFUs that can be accounted for as a result of the successful completion of the activity; as a rule of thumb, assume 1 CFU = 20 working hours.
³ Please insert lines as required/appropriate, and for each line complete each column of the Table.
⁴ Indicate here the CFUs that can be accounted for as a result of the successful completion of the activity; as a rule of thumb, assume 1 CFU = 20 working hours.
<table>
<thead>
<tr>
<th>Insert the title of the activity and a description of goals and expected results.</th>
<th>Insert here activity type (e.g. course, seminar, lab, tutorial)</th>
<th>Insert here the duration of the activity (measured in full days of work) and the period of the year when it will be carried out</th>
<th>Insert here a detailed explanation of why the activity was selected and included in the program form, taking into account the research area of the PhD candidate, any previous activity related to the one being proposed, and specific interest of the candidate in the topic covered by the activity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and implementation of a Deep Reinforcement Learning framework on a FPGA device.</td>
<td>Laboratory</td>
<td>Mar. – Jul. 2019 100 hours</td>
<td>The candidate developed a novel adaptive routing algorithm (DQN Adaptive Routing) based on the usage of deep neural networks in a reinforcement learning framework (Deep Reinforcement Learning). With this activity he will gain insight on how to implement this architectural block on a FPGA, paving the way to the implementation of the DQN Adaptive Routing in the ExaNeSt network.</td>
</tr>
<tr>
<td>4th International Workshop on Advanced Interconnect Solutions and Technologies for Emerging Computing Systems (AISTECS) 2019</td>
<td>Workshop</td>
<td>1 (January 2019) 0.5</td>
<td>This workshop aims at bringing together researchers and engineers from industry and academia to share ideas and thoughts about networking of devices in both the off-chip and the on-chip environment, each with its own design constraints.</td>
</tr>
<tr>
<td>QCA: Tutorial on Quantum Computer Architecture (HIPEAC 2019 Conference).</td>
<td>Tutorial</td>
<td>1 (January 2019) 0.5</td>
<td>Quantum computers hold the promise for solving efficiently important problems in computational sciences that are intractable nowadays by exploiting quantum phenomena such as superposition and entanglement. This tutorial will introduce the basic notions of quantum computing; going from quantum bits, superposition and entanglement, to quantum gates and circuits, up to quantum algorithms. The tutorial will provide hands-on exercises based on our QX simulation platform (<a href="http://quantum-studio.net">http://quantum-studio.net</a>) and some examples using the OpenQPL programming language/compiler. This will allow the participants to implement some simple quantum circuits/algorithms. The main challenges and the current implementation when building a small or large-scale quantum computer will also be addressed.</td>
</tr>
</tbody>
</table>

**Total CFU**

6

**RESEARCH ACTIVITY: 42 CFU**

**Research area**

Interconnection Network Architectures for High-Performance Computing.

**Research topic**

Adaptive Routing Techniques for n-dimensional Torus Networks.

**Framework of the proposed research topic**

With the current VLSI technology, about $10^{18}$ high end processor nodes have to be assembled in order to build a High Performance Computing (HPC) system capable of at least one exaFLOPS ($10^{18}$ floating point operations per second) and to enter the domain of Exascale computing. This is considered as a fundamental milestone in computing achievement that will have a great impact on many scientific and technological fields.

It is well known that the sustained computing power of HPC systems depends dramatically on the efficiency of their interconnection network when scaling to high number of processor nodes. The EU H2020 ExaNeSt project aims at designing the system architecture for Exascale class HPC parallel machines characterized by a highly scalable three-tier interconnection architecture: intra-node tree network, inter-node torus direct network and an optional top tier indirect network. During the architectural exploration phase of the project, 2D/3D/4D torus network interconnecting up to thousands of computing nodes will be considered for the tier-1 level.

The research activity will be focused on the development of a novel adaptive routing algorithm based on reinforcement learning techniques for the tier-1 network of the ExaNeSt architecture. With the objective of minimizing the workload completion time, this novel algorithm should allow to adapt routing decisions at runtime according to the network traffic pattern generated by the specific computational task under execution. Furthermore, interacting with a pre-existent fault-awareness system, it should provide a fault-reaction mechanism for failures in the network (channels and routers).

The performance of the novel adaptive algorithm will be benchmarked executing Human Brain Project simulation codes of Spiking Neural Networks and other selected scientific codes both on a simulator and on parallel machines based on ExaNet computing nodes interconnected by 2D/3D/4D torus networks.
The research activities will be carried out in the context of ExaNeSt (2015-2019), EuroEXA (2017-2021) and Human Brain Project-SP3 WaveScales (2016-2023) projects.

The ExaNeSt project, started on December 2015 and funded in EU H2020 research framework (call H2020-FETHPC-2014, n. 671553), is a European initiative aiming to develop the system-level interconnect, a fully-distributed NVM (Non-Volatile Memory) storage and the cooling infrastructure for an ARM-based Exascale-class supercomputer. The ExaNeSt Consortium combines industrial and academic research expertise, in the areas of system cooling and packaging, storage, interconnects, and the HPC applications that drive all of the above: Istituto Nazionale di Fisica Nucleare (INFN), Istituto Nazionale di Astrofisica (INAF), EnginSoft S.p.A. and eXact lab srl for Italy, Foundation for Research and Technology - Hellas (FORTH) for Greece, Universitat Politècnica de València for Spain, Virtual Open Systems for France, Fraunhofer Institute for Mathematics (ITWM) for Germany, MonetDB Solutions for the Netherlands, University of Manchester, Iceotope Technologies Ltd and Allinea Software Ltd for the UK.

The H2020 FET-HPC-2016 EuroEXA project started on September 2017 picks up the banner of a triad of partner projects — ExaNeSt, EcoScale and ExaNoDe — building on their work to develop a complete HPC system based on ARM Cortex processors and Xilinx Ultrascale FPGAs. The goal is to deploy an energy-efficient petaFLOPS system by 2020 and lay a path to achieve exascale capability in the 2022-23 timeframe. The project is coordinated at the Institute of Communication and Computer Systems in Greece and has 15 project partners across eight countries:

Spain — Barcelona Supercomputing Center
United Kingdom — ARM-UK, Iceotope, Maxeler Technologies, The University Of Manchester, The Hartree Centre of STFC, ECMWF (European Centre For Medium-Range Weather Forecasts)
Greece — FORTH (Foundation For Research And Technology Hellas), Synelixis Solutions Ltd
Belgium — IMEC
Sweden — ZeroPoint Technologies
Netherlands — Neurasmus
Italy — INFN (Istituto Nazionale Di Fisica Nucleare), INAF (Istituto Nazionale Di Astrofisica)
Germany — Fraunhofer-Gesellschaft

The WaveScales experiment, led by the INFN, is performed by a team of five research institutes. Three of the partners are specialised in experiments on the human brain and the brains of rodents, the other two will concentrate on developing theoretical models and computer simulations. The INFN’s APE lab will combine its DPSNN simulation engine and the HBP platforms to develop the large scale neural WaveScales simulator, which will mimic the behaviour generated by several tens of billions of nerve cell connections, or synapses. The partners in the experiment will measure the slow cerebral waves propagated in the cortex during deep sleep and the waking state, and observe the cortical response to localised spatio-temporal perturbations. The experimental techniques used will include non-invasive observations in humans, such as high resolution electroencephalographic response to transcranial magnetic stimulation, performed by the team led by Marcello Massimi at the University of Milan, and electrophysiological measurements on rodents in response to opto-pharmacological stimulations, conducted by teams led by Maria Victoria Sánchez-Vives, from the Institut D’Investigacions Biomèdiques August Pi i Sunyer (IDIBAPS) in Barcelona, and by Pau Gorostiza, from the Institut de BioEnginyeria de Catalunya (IBEC), also in Barcelona. The theoretical models will be developed by the Italian Institute of Health (ISS - Istituto Superiore di Sanità), under the direction of Maurizio Mattia and Paolo Del Giudice.