Scale-FreeBack
Advanced Grant 2015
Scale-Free Control for Complex Physical Network Systems

Scale-Free Modelling and Control for Large Scale Complex Networks

Supervisors: Carlos Canudas-de-Wit (DR-CNRS, supervisor), **Sandro Zampieri** (co-supervisor).
Context: ERC-AdG Scale-FreeBack (see http://scale-freeback.eu)
Application type: Post-doc. Gross salary: 2530-3509(if more than 2 year after PhD) Euros/M
Duration: 12+12 months. **Employer**: CNRS. **Location**: Grenoble, France
Applications: http://scale-freeback.eu/openings/
Collaboration: In collaboration with Prof. Zampieri (Padova University). Several trips planned to Padova.

Context. **Scale-FreeBack** is an ERC Advanced Grant 2015 awarded to Carlos Canudas-de-Wit, Director of Research at the National Center for Scientific Research, (CNRS), during Sept. 2016-2021. The ERC is hosted by the CNRS. The project will be conducted within the NeCS group (which is a joint CNRS (GIPSA-lab)-INRIA team). Scale-FreeBack is a project with ambitious and innovative theoretical goals, which were adopted in view of the new opportunities presented by the latest large-scale sensing technologies. The overall aim is to develop *holistic scale-free control methods of controlling complex network systems in the widest sense, and to set the foundations for a new control theory dealing with complex physical networks with an arbitrary size*. Scale-FreeBack envisions devising a complete, coherent design approach ensuring the scalability of the whole chain (modelling, observation, and control). It is also expected to find specific breakthrough solutions to the problems involved in managing and monitoring large-scale road traffic networks. Field tests and other realistic simulations to validate the theory will be performed using the equipment available at the Grenoble Traffic Lab center (see GTL), and a microscopic traffic simulator replicating the full complexity of the Grenoble urban network. The proposed work will be undertaken in the context of this project.

Topic description. This research proposal deals with the problem of setting up a suitable modelling framework for complex systems corresponding to large-scale networks. The original system is assumed to describe a homogenous network in which the node/link distribution is a bell-shaped, exponentially decaying curve. Homogenous networks cover many critical systems of interest (such as road traffic networks, power grids, water distribution systems, etc.), but are inherently complex. Scale-FreeBack is elaborated on the idea that complexity can be broken down by abstracting an aggregated scale-free model (represented by a network with a power law degree distribution), by merging/lumping neighboring nodes in the original network. In that, supper-nodes (nodes with a lot of connections) are created and represented by "aggregated" variables. Controlling only boundary inputs and observing only aggregated variables allows to cut-off the system complexity. The following questions will be addressed:

1) Defining the most suitable level of aggregation for the model. This boils down to defining and sizing the state-vector, the control inputs and outputs. A first question is how to define the right level of aggregation, and investigate new metrics trading quantifiers reflecting an optimal level of scalability (a suited node/link distribution) of the associated network graph, with other performance indexes reflecting the system's closed-loop operation.

2) The second question focuses on how the aggregation process, in addition to the scale-free property, will yield models consistent with the design of control and the observation goals. The aggregation process will have to include *observability and controllability properties* which are consistent with the evolutionary nature of scale-free aggregated models (aggregation process is evolutionary in the sense that the network changes and so the aggregated modules will change accordingly while preserving the scale-free properties).

3) Finally, innovative concepts such as *peripheral controllability* (i.e. controlling the boundary flows in a lumped node rather than controlling each single node separately), and *energy-weighted controllability metrics* (where controllability is qualified by assessing the energy costs as a function of the controllable nodes [Zam-et-al'14]) will be extended in this project to the context of scale-free models. While only open loop metrics have been considered so far, we aim to propose new closed loop metrics also taking inspiration from road traffic networks application. Finally, we will propose and investigate different new weak notions of controllability in which the controllability is determined with respect to a limited subspace (peripheral and/or sparse controllability), and to devise the associated control methods.

Request Background. Control Systems, Applied mathematics.
Applications. Please follow the application procedure indicated at (http://scale-freeback.eu/openings/)

[Zam-et-al'14] Fabio Pasqualetti, Sandro Zampieri, and Francesco Bullo. "Controllability Metrics, Limitations and Algorithms for Complex Networks". *IEEE Trans on Control of Network Systems*, Vol:1 , Issue: 1 , March 2014, pp-40-52.