

CRII: CPS: Architecture and Distributed Computation in the Networked Control Paradigm: An Autonomous Grid Example

Abstract

This project is focused on the fundamental research in establishing a foundational framework towards the development of an autonomous Cyber-Physical System (CPS) through distributed computation in a Networked Control Systems (NCS) paradigm. Specific attention is focused on an application where the computational, and communication challenges are unique due to the sheer dimensionality of the physical system. An example of such CPS is the smart power grid, which includes large-scale deployment of distributed and networked Phasor Measurement Units (PMUs) and wind energy resources. A systematic approach is proposed for wide-area oscillation damping control, which can handle data packet dropout in the communication channels in such smart power grids. The major challenges identified in the controller design are: a) computational burden, b) communication network delays and data drops. To handle the challenges of computational burden, frequency-domain abstraction is explored to reduce the dimension of the model. To that end, it is demonstrated that the accuracy of the widely-used Balanced Truncation (BT), Subspace Accelerated MIMO Dominant Pole (SAMDP), and Iterative Rational Krylov algorithm (IRKA) worsens in producing MIMO reduced order model (ROM) when modern grid with wind generation is considered. A Heuristic Iterative Rational Krylov Algorithm (H-IRKA) is proposed, which improves the accuracy, while ensuring explicit preservation of the critical eigenvalues of the system. To handle the delays and data drops the dynamic property of the ROM is exploited in an Observer-driven Reduced Copy (ORC) framework. Nonlinear time-domain simulations following large disturbances (e.g., faults, line outages, etc.) demonstrate that the ORC gives significantly better performance compared to conventional feedback under higher data drop situations. The key contribution comes from the analytical derivation of a bound indicating the impact of coupling between the cyber and the physical layer on ORC performance. It is shown that the uncertainty in the cyber layer due to data packet drop and the off-nominal operation of the physical layer affect the ORC performance in a coupled manner, where the coupling is non-trivial. A second performance bound is also proposed, which is based upon bound on the norm of the difference between the power system states in presence of data dropout and that under ideal communication within an inter-sample interval.