Network-Level Design of Cyber-Physical Networks-of-Systems

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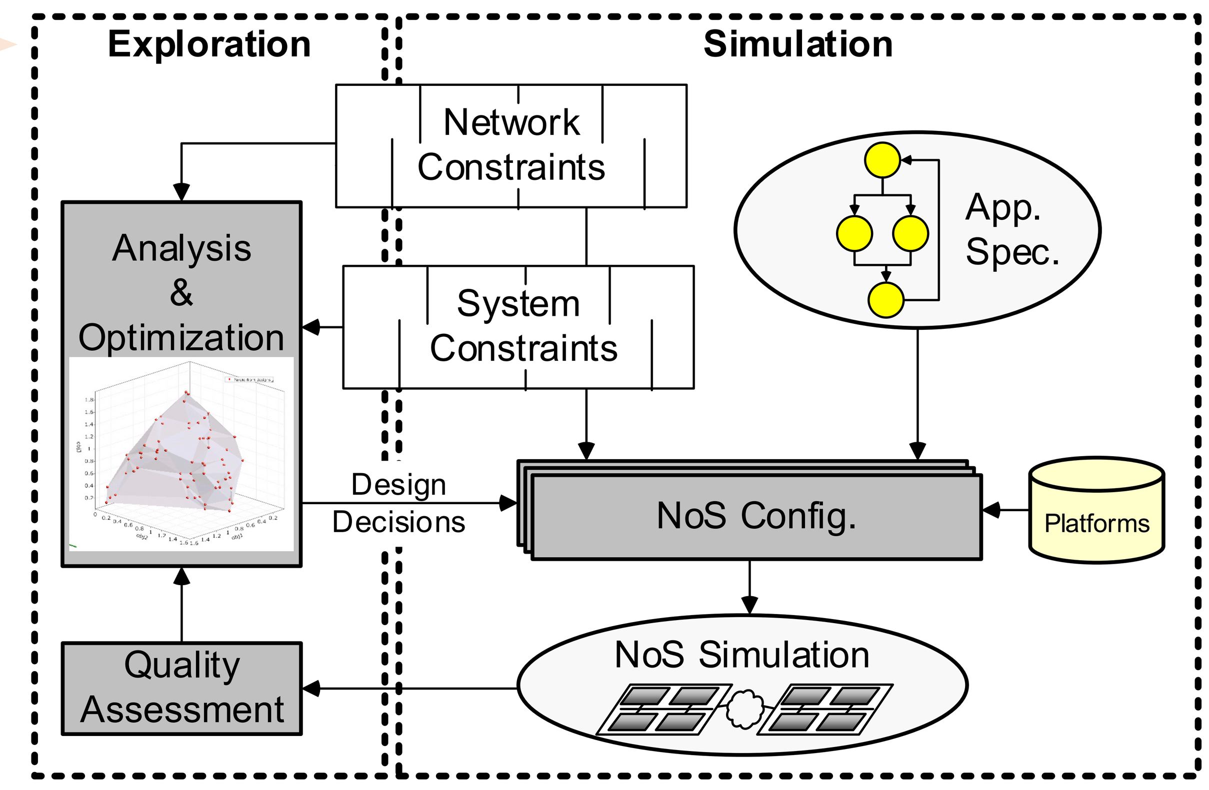
Overview

Motivation & Objectives

- Increasingly networked cyber-physical systems
  - Internet of Things (IoT), Wireless Sensor Networks (WSNs)
  - Distributed data collection, aggregation and processing
- Tight computation and communication coupling
  - Non-obvious interactions and tradeoffs
  - Traditionally networks and systems are designed in isolation
  - Ignores joint optimization challenges and opportunities
- ➢ Systematic computation/communication co-design
  - Comprehensive design space exploration
  - Joint consideration of design parameters from applications to network configurations and system platform definitions

Design Flow

- From network-level specification
  - Formal models of computation and communication for high-level network-of-systems (NoS) specification
  - Exposing network uncertainties
  - Dynamic aspects of adaptivity and reactivity
- To networked system implementation
  - Network and system co-design
  - Architecture definition and application mapping
  - Fast yet accurate network-of-systems (NoS) simulation for validation, prototyping and exploration
- ➢ Specification & implementation models for NoS design automation

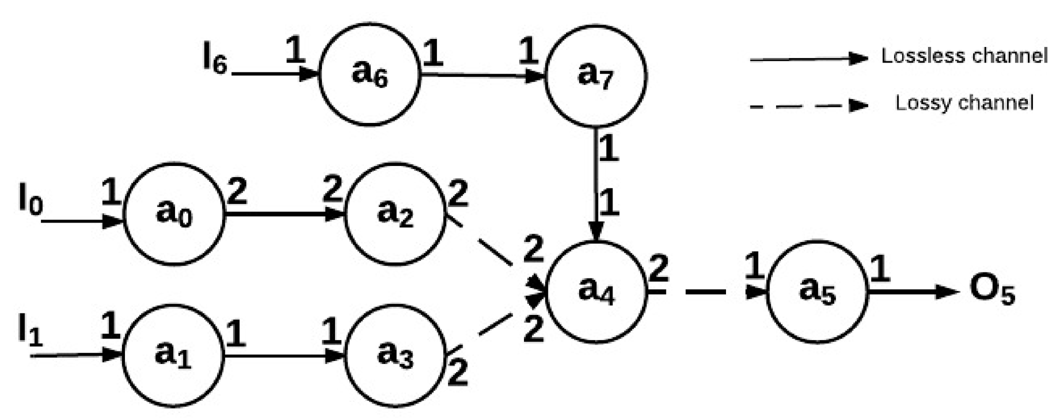


Network-of-Systems (NoS) Specification

Motivation

- Traditional models
  - Models of computation require lossless communication and can not simultaneously capture streaming and reactive behavior
  - Models of communication support richer network semantics but do not account for expressing system computation & concurrency
- ➢ Unified models of computation and communication (MoCC) for NoS specification

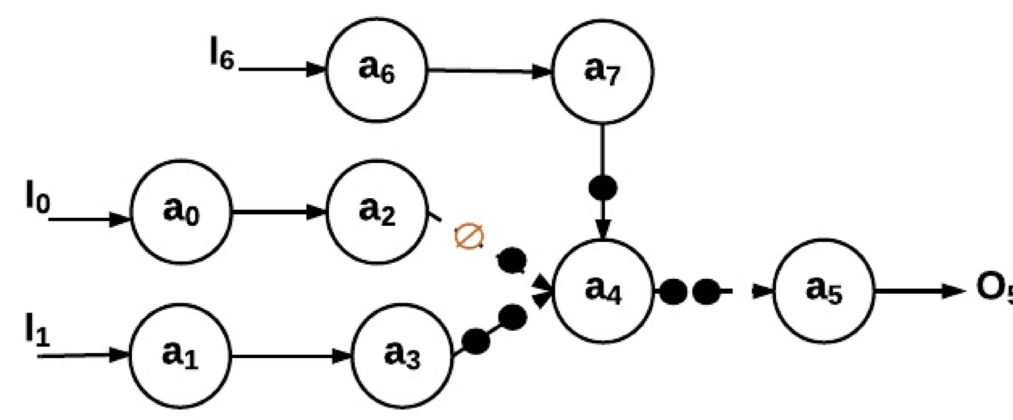
Reactive and Adaptive Dataflow (RADF)



- Extension of existing (synchronous) dataflow models
- Empty tokens (ø)
  - Lost data and absence of sporadic events in input patterns
  - Maintain guaranteed determinism
- Actor variants
  - Different variants per token patterns
  - Idle version executed when input patterns are all empty-tokens

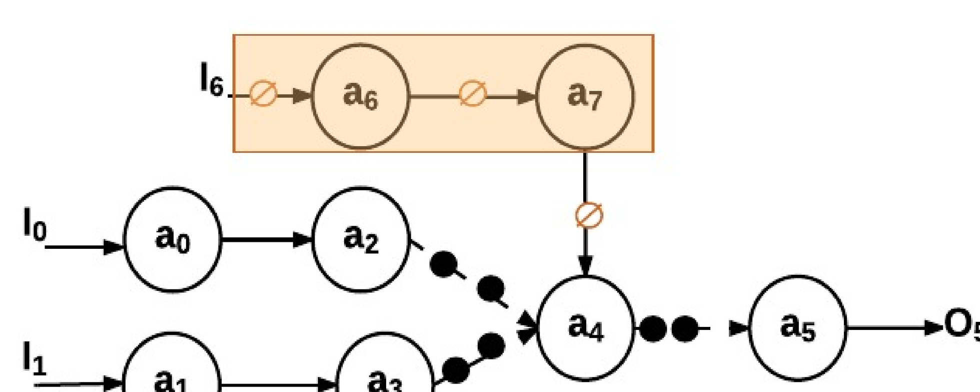
Adaptivity

- Empty tokens and actor variants: expose network losses to the application level



Reactivity

- Reactive island: firing idle variant of source actor triggers all subsequent connected actors to fire their idle variants



Performance Analysis

- Worst-case throughput and latency
- Conversion to scenario-based/modal model leads to exponential complexity
  - Account for all possible actor variant combinations
- ➢ Calculate throughput & latency of the graph formed by taking the WCET of each actor
  - Lossy channels isolate actor variants
  - Might under-estimate the worst-case

Future Work

- Implementation of RADF semantics
  - Multiple distributed implementation choices
- Analysis techniques for probabilistic performance metrics
  - Tradeoff between latency, throughput and QoS versus token loss probability

References

- S. Francis and A. Gerstlauer, "A Reactive and Adaptive Data Flow Model for Network-of-System Specification", *IEEE ESL*, 2017. (under review)

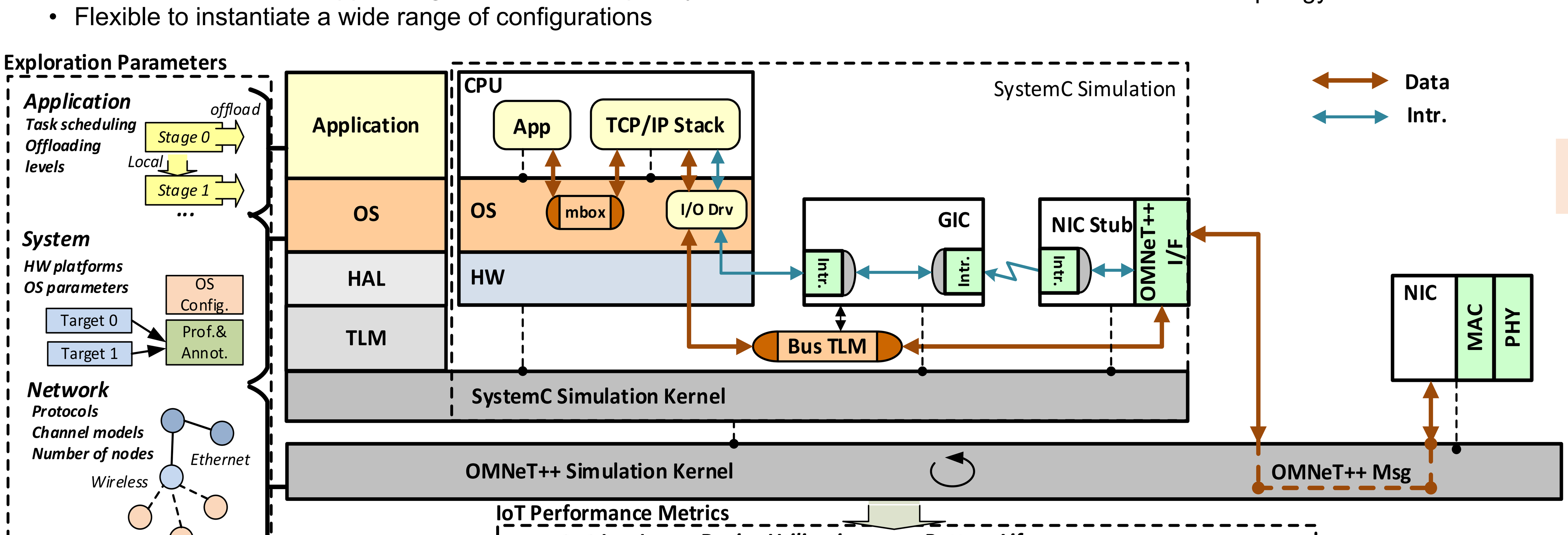
Network-of-Systems (NoS) Simulation

Motivation

- Traditional system models
  - Transaction-level platform models combined with instruction-set or source-level/host-compiled software simulation
  - Over-simplified or no network channels/protocols
- Traditional network models
  - Analytical queuing, stochastic or network calculus models
  - Discrete event-based network simulators
  - Over-simplified system models
- ➢ Network/system co-simulation
  - Capture and emulate complicated system/network interactions
  - Fast and accurate to support large scale and complexity of NoS
  - Flexible to instantiate a wide range of configurations

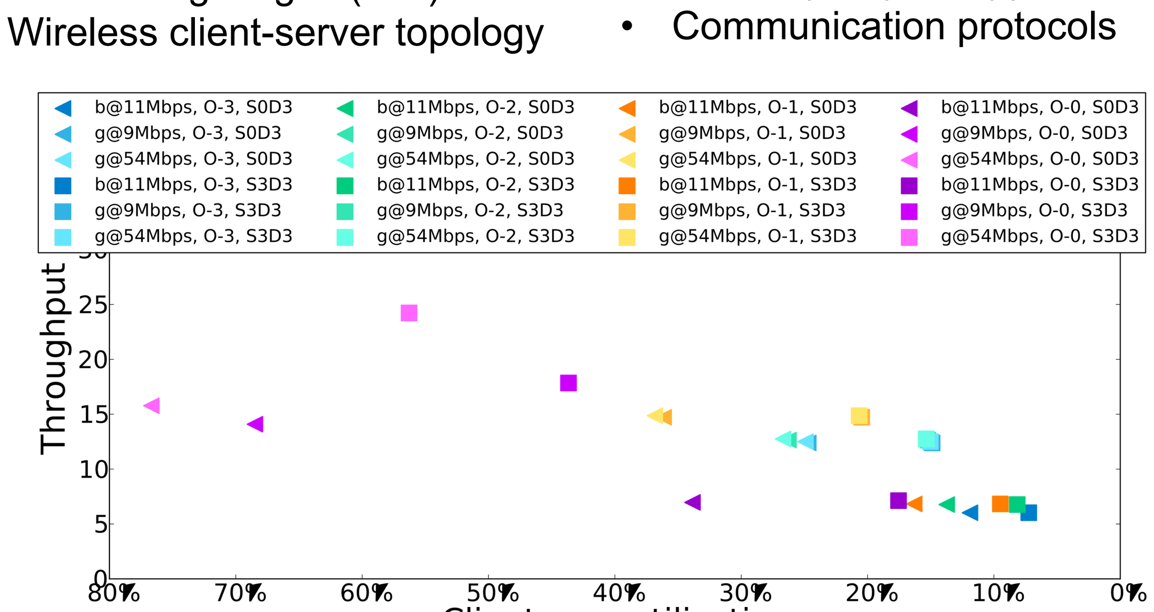
Host-compiled NoS Simulator

- Host-compiled (HC) system simulator
  - Source-level back-annotated application model
  - Abstract operating system (OS) model
  - Network stack model (lwIP)
  - SystemC transaction-level modeling (TLM) base
- Network simulation backplane
  - OMNeT++ network simulator
  - INET package for media access (MAC) and physical (PHY) layer simulation
  - Host-compiled SystemC device instances in an overall OMNeT++/INET network topology



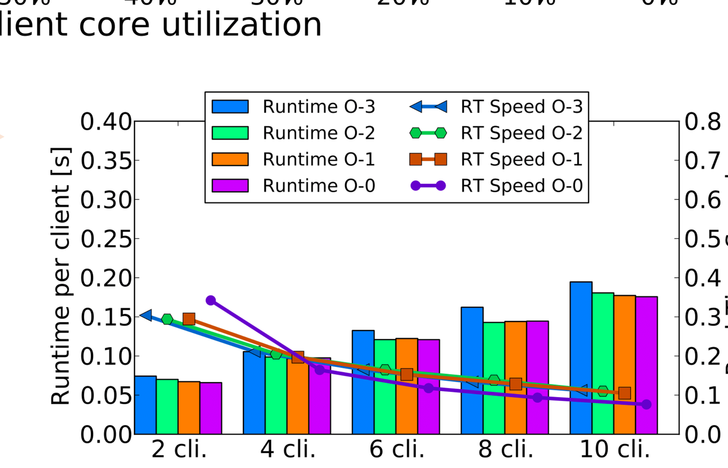
NoS Design Space Exploration

- IoT application case study
  - ECG diagnosis application
  - 4 offloading stages (O-*n*)
  - Wireless client-server topology
- System/network parameters
  - Client/server core types and counts (SxSy/SxDy)
  - Communication protocols



Simulator Speed

- Simulation speed
  - >0.18 simulated sec / real sec on average



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- Z. Zhao, A. Gerstlauer, L. John, "Source-Level Performance, Energy, Reliability, Power and Thermal (PERPT) Simulation," *IEEE TCAD*, 36(2):299-312, February 2017

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