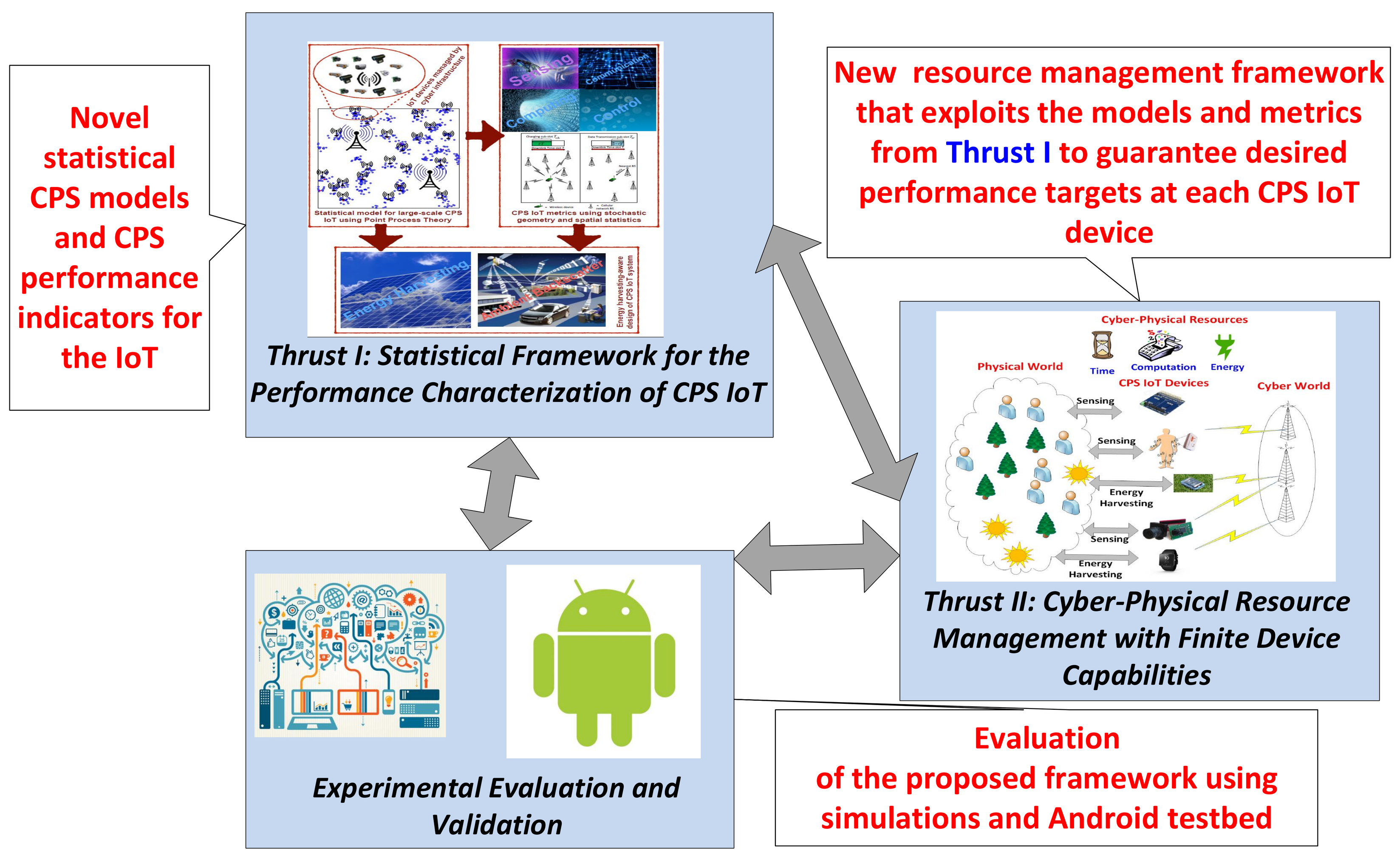
Statistical Performance Analysis and Resource Management for Cyber-Physical Internet of Things Systems

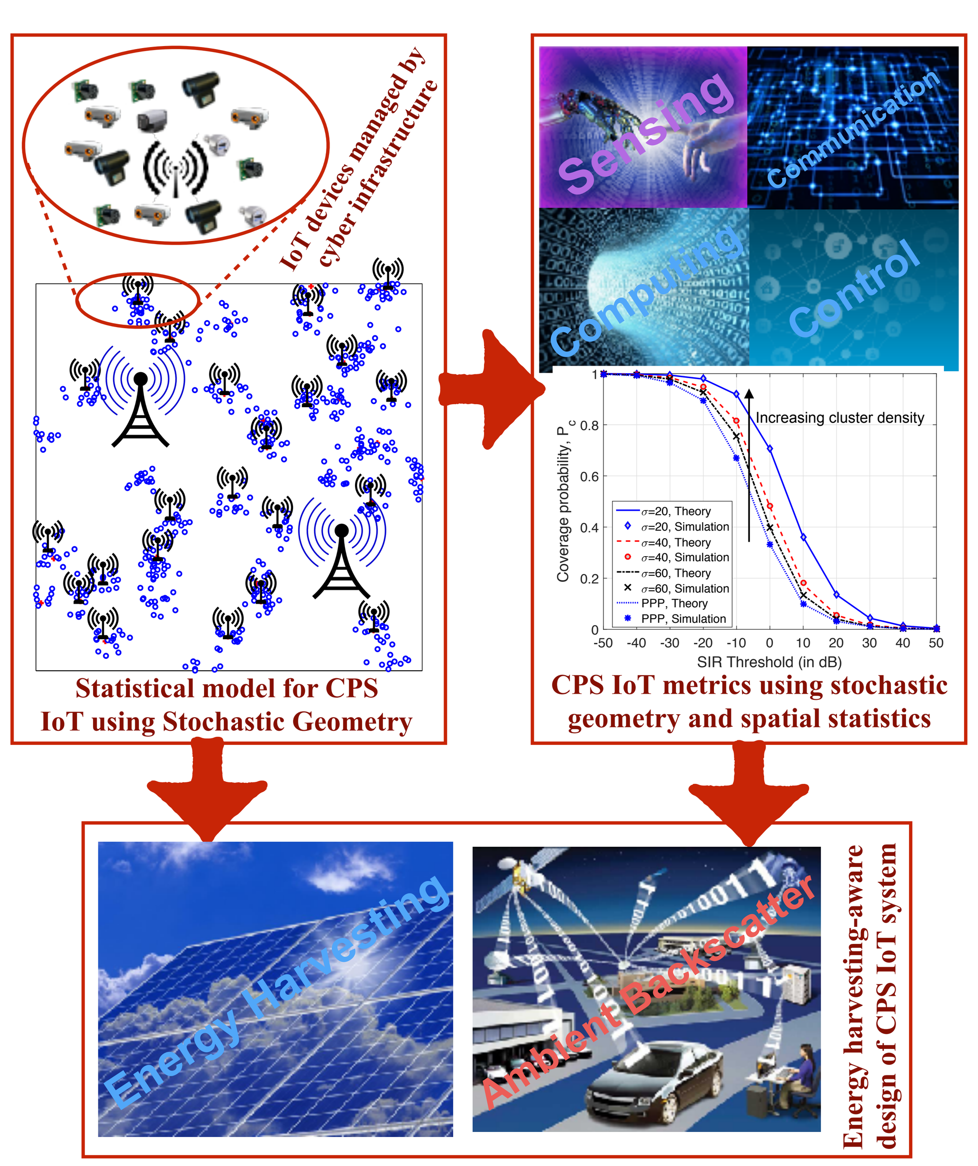
Virginia Tech: Harpreet S. Dhillon (PI), Walid Saad (Co-PI)

Project Overview

Project Goal: Develop novel CPS science that will enable modeling, designing, and optimizing the IoT as an integrated cyber-physical system while turning the relationships between its cyber and physical elements into system-wide efficiency.



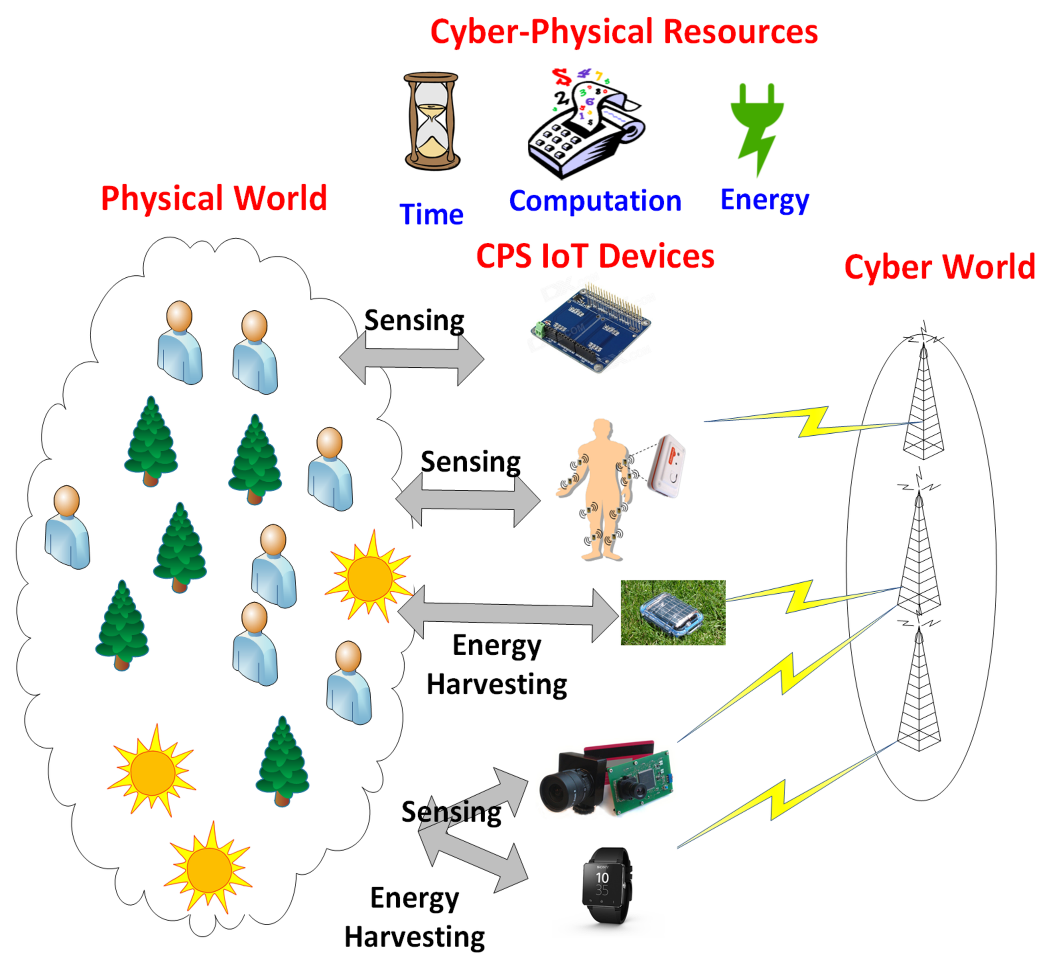
Thrust I: Statistical Framework for the Performance Characterization of CPS IoT



Main Tasks

- Statistical model for the CPS IoT system using tools from stochastic geometry.
- Specialized CPS IoT performance metrics to model and understand joint cyber and physical performance limits.
- Design and analysis of energy harvesting-aware CPS IoT in which the IoT devices may have the capability of harvesting energy from ambient sources, such as RF.

Thrust II: Cyber-Physical Resource Management with Finite Device Capabilities



Key Question of Thrust II

How to allocate resources such as time, communications, computation, and energy across the cyber and physical functions of CPS-IoT devices?

Main Tasks

- Using distributed optimization tools to optimize joint management of cyber and physical resources.
- Development of learning mechanisms that can be run by devices with finite resources, memory, and energy capabilities.
- Analysis of large-scale CPS-IoT systems using statistical physics and related areas.

Broader Impacts

Curriculum development and student training: Results incorporated in the graduate-level Game Theory for Communications Networks course. Graduate students were trained on all aspects of research as a part of this project.

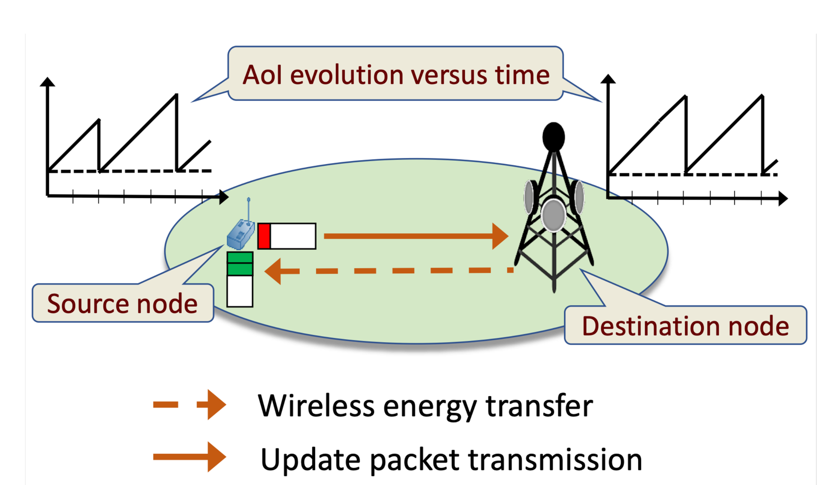
Outreach and diversity: PIs and the graduate students participated in outreach events organized by Center for Enhancement of Engineering Diversity at Virginia Tech. For instance, they provided educational experiments on the IoT within the *Imagination Summer Camp* for middle/high school girls.

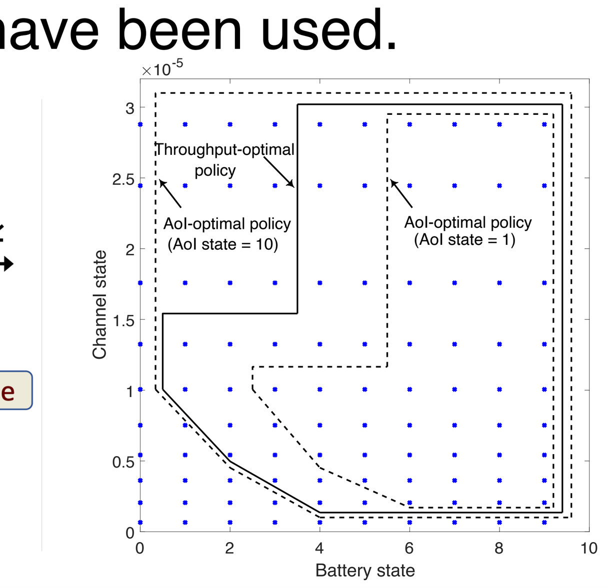
Dissemination: This research was disseminated through tutorials, invited seminars, as well as using traditional dissemination methods (such as journal and conference papers). The two PIs are also editing a Cambridge University Press book on Age of Information that is inspired by this project.

Age of Information for CPS IoT

Freshness of information plays a crucial role in the design of CPS IoT. Age of information has recently emerged as a new metric to quantify this freshness.

New results on *Age of Information*: This project has provided multiple fundamental insights about age of information in CPS IoT, such as the structure of *age-optimal policies* in an RF-powered IoT in which the IoT devices are powered through wireless energy transfer from the base stations. Tools from Markov decision processes, deep reinforcement learning, and most recently stochastic geometry have been used.

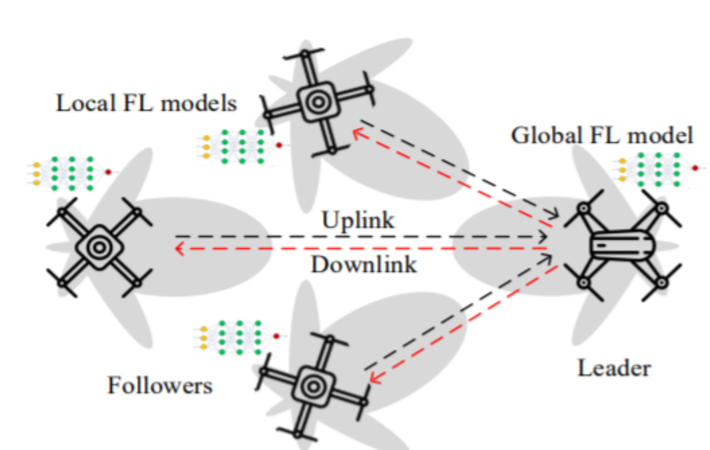


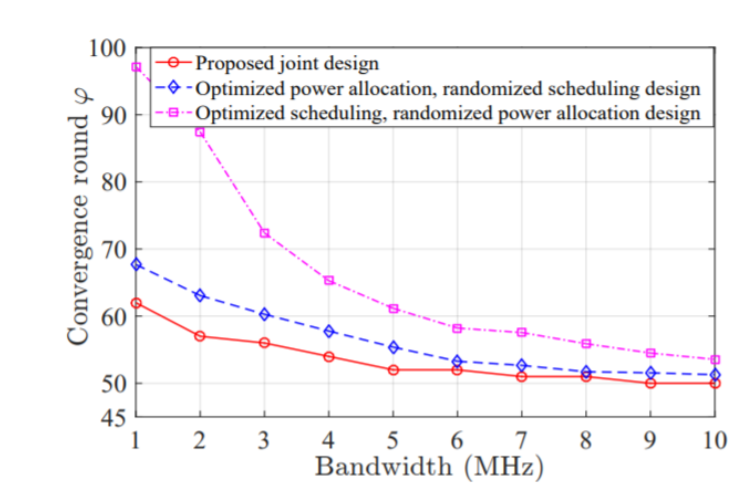


Distributed Learning in the Sky

Swarms of UAVs will be a central component of a CPS IoT. What if swarms can perform joint learning?

New results on *joint communications, control, and learning with swarms*: We analyzed convergence of federated learning (FL) for swarms. Using key insights on how wireless affects FL in swarms, we posed an optimization problem that jointly designs the power allocation and scheduling for the UAV swarm to speed up FL convergence while factoring in energy efficiency and control system stability constraints. Simulation results show that the joint design can reduce the convergence round by as much as 35% compared with baselines without the joint design





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